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METHODS FOR UPGRADING SOME ALBERTA COALS

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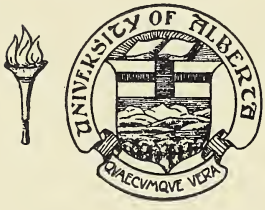


UNIVERSITY OF ALBERTA

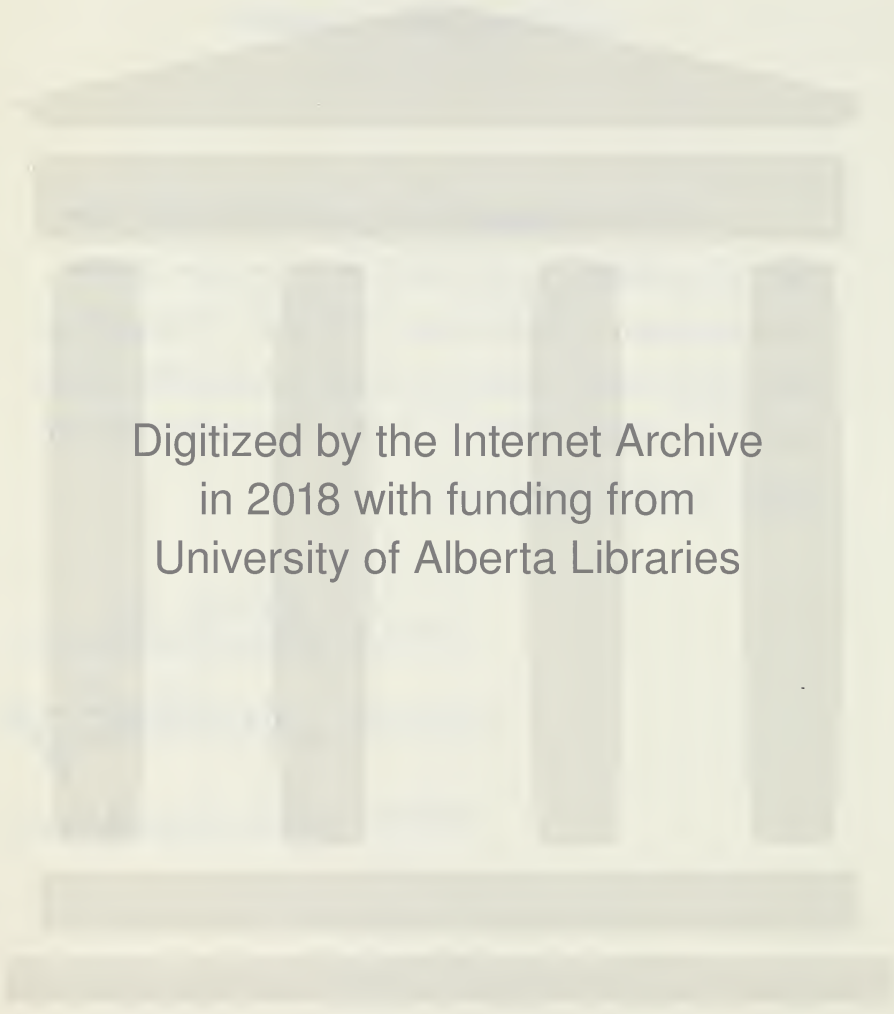
FACULTY OF ARTS AND SCIENCES

The undersigned hereby certify that they have read and recommend to the Committee on Graduate Studies for acceptance, a dissertation on "Methods for Upgrading Some Alberta Coals" submitted by Raymond Alexander Leask, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

Professor

Professor

Professor



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METHODS OF UPGRADING SOME ALBERTA COALS

by

Raymond Alexander Leask, B.Sc.

Research Council of Alberta
University of Alberta

A Thesis

Submitted to the University of Alberta
in partial fulfilment of the requirements
for the degree of Master of Science.

Edmonton, Alberta April, 1947

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Thesis
1947
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PREFACE AND ACKNOWLEDGEMENTS

The investigations described in this thesis were carried out in the laboratories of the Research Council of Alberta, under the supervision of Mr. Edgar Stansfield, Chief Chemical Engineer (now retired), and Mr. W.A. Lang, Senior Research Chemist, to whom the writer wishes to acknowledge his indebtedness for advice and assistance throughout the work, and to Mr. A. McCulloch, Chief Chemical Engineer, for kindly criticism in the preparation of this manuscript.

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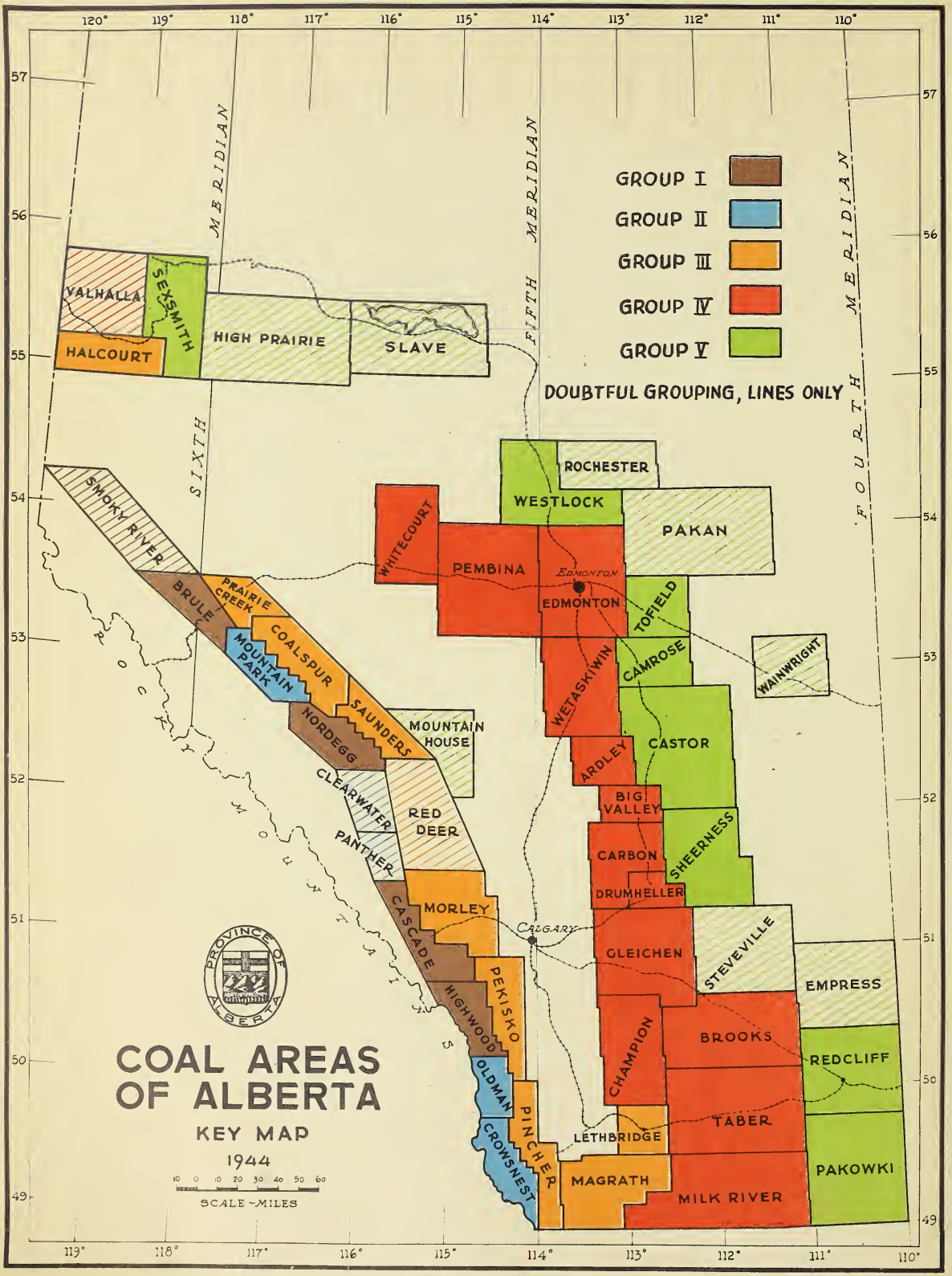

120° 119° 118° 117° 116° 115° 114° 113° 112° 111° 110°
57 56 55 54 53 52 51 50 49
SIXTH MERIDIAN
FIFTH MERIDIAN
FOURTH MERIDIAN
GROUP I
GROUP II
GROUP III
GROUP IV
GROUP V
DOUBTFUL GROUPING, LINES ONLY
VALHALLA
SEXSMITH
HALCOURT
HIGH PRAIRIE
SLAVE
ROCHESTER
WESTLOCK
PAKAN
WHITECOURT
PEMBINA
EDMONTON
TOFIELD
WAINWRIGHT
CAMROSE
WETASKIWIN
CASTOR
ARDLEY
BIG VALLEY
SHEERNESS
CARBON
DRUMHELLER
SMOKY RIVER
PRAIRIE CREEK
BRULE
COALSPUR
MOUNTAIN PARK
SAUNDERS
NORDEGG
MOUNTAIN HOUSE
CLEARWATER
PANTHER
RED DEER
MORLEY
CASCADE
HIGHWOOD
PEKISKO
OLDMAN
CROWSNEST
PINCHER
CALGARY
GLEICHEN
STEVEVILLE
EMPRESS
CHAMPION
BROOKS
REDCLIFF
TABER
LETHBRIDGE
MAGRATH
MILK RIVER
PAKOWKI
ROCKY MOUNTAINS
PROVINCE OF ALBERTA
COAL AREAS OF ALBERTA
KEY MAP
1944
10 0 10 20 30 40 50 60
SCALE - MILES

PLATE I

METHODS FOR UPGRADING SOME ALBERTA COALS

General Introduction

The Province of Alberta has large reserves of coal[1,] ranging in rank, according to the A.S.T.M. Coal Classification System[3], from semi-anthracite through the bituminous and subbituminous coals to lignite. The higher rank coals occur in the mountain and foothill regions of Alberta, the rank progressively decreasing with the distance from the mountains and in a line roughly parallel to the mountain range. The extent of coalification apparently has been due more to the pressures exerted laterally during the upthrust which resulted in the formation of the Rocky Mountains than to the geological age of the coal beds. Generally speaking, coals appear in three distinct geological horizons, namely, the Edmonton, the Belly River and the Blairmore-Kootenay[4]. The first two horizons are in the Upper Cretaceous and the third in the Lower Cretaceous.

For analytical details of the composition and for the characteristics of the various coals in the several districts of the three formations, reference should be made to Report #35 of the Research Council of Alberta. For ready references, however, Alberta coals have been placed in five main groups[2] which are briefly:

Group I - Low volatile, non-coking, bituminous coals from mountain areas.

Group II - High volatile, coking, bituminous coals from mountain areas.

Group III - Subbituminous coals, principally from the foothills areas.

Group IV - Domestic coals possessing fair storage properties, from the prairies.

Group V - Domestic coals possessing poor storage properties, from the prairies.

Plate I shows the distribution of the coals in the Province according to their position in the separate groups.

The generalization that the rank of the coals decreases progressively according to their distance from the mountain barrier cannot be interpreted too literally. Plate I shows that in the Mountain Park, Oldman and Crowsnest areas the coals are essentially of a coking type whereas those in the Highwood, Cascade, Nordegg and Brule areas are non-coking low volatile coals. The geographic distribution of the coking coals is naturally of considerable economic importance and attention is drawn to it at this early stage since in the experimental work on briquetting described later in this thesis, coals of a coking nature have been used to a considerable extent.

Not only do the coking qualities of the various coals differ according to the Provincial districts in which they are mined but also their physical characteristics. Those coals which were subjected to the greatest disturbance during the mountain building period are much more fractured and friable than coals in the less disturbed areas, i.e. the plains. In many of the former cases, bands of slate and shale have become so intimately mixed with the coals that separation in the

actual course of mining is impossible. On the other hand most of the coal seams in the prairies lie in a relatively undisturbed condition. They commonly contain lenses or bands of clay and shale which can be readily discarded during mining. In other instance, however, shale and clay become invariably mixed with the coal during mining operations.

Whilst coals occur in Alberta which are suitable for most domestic and industrial purposes, the tonnage actually mined is naturally limited by the available markets. The Province of Alberta is distant from the more thickly populated and industrialized eastern areas of Canada and the cost of transportation, therefore, becomes an exceedingly important factor in considering the marketing of Alberta coals. Within the Province, there are very large reserves of natural gas which continues to displace coal largely owing to its availability of supply, cleanliness in operation and the ease with which the quantity used can be controlled automatically in both domestic and industrial processes of utilization. With the development of hydro-electric power in the Province, the electrical distribution systems are being extended and accordingly there are cases in which local power plants burning slack coal have been closed owing to ample supplies of electricity being made available which is cheaper or which for other reasons is preferable to use. The generation of hydroelectric power and its wider distribution, as well as a marked tendency for coal consumers to favor oil fuels, has heightened the interests of the colliery industry in the problems associated with the improvement or upgrading of solid fuels, both for domestic and industrial purposes.

By the term "upgrading of coal" I refer to any process whereby a higher quality of coal can be obtained. Upgrading may include the preparation of a better sized product; a product substantially free from fine material; or a product with a higher heat value or improved coking or combustion characteristics. Thus coal may be upgraded during its mining, its preparations for the market or by further processing after it leaves the colliery premises.

In the work described in this thesis, studies have been made of three methods of upgrading coals, namely, upgrading by coal washing, upgrading by briquetting with a suitable binding agent and upgrading by briquetting followed by a process of low temperature carbonization. For these studies the following coals have been used:

(a) Drumheller coal - for washing and for briquetting followed by low temperature carbonization.

(b) Camrose coal - for briquetting followed by low temperature carbonization.

(c) Nordegg coal - for washing and for briquetting.

(d) Luscar coal - for briquetting.

(e) Crowsnest coal and Mountain Park coal - for blending purposes in briquetting followed by low temperature carbonization.

In the Drumheller area, of the Edmonton formation, which is one of the principal mining districts of Alberta, the coals fall into Group IV, that is to say, these coals are high volatile subbituminous coals of high moisture and oxygen contents entirely devoid of coking properties. According to Report #13 of the Research Council of Alberta[5], there appear to be three principal seams which have been worked at all extensively in this area, namely, the Drumheller seam,

Seam No. 1; Seam No. 2; and the Top or Newcastle seam, Seam No. 5.

The seam source of the Drumheller coal used in the experimental work was not known but since the coal came from the Midland Mine, it is assumed that probably the coal was at least principally from the Drumheller or No. 1 seam. This seam is divided into two portions by a band of bentonite which varies in thickness from one inch to twenty inches. In some cases the bentonite band is underlain by a band of bone or coaly bone or hard granular coal. In certain mines the band is too wide to warrant its extraction and the lower bench of coal is left in the mine.

The coal above the bentonite, varying in thickness from five feet to six feet four inches contains, in places, one or more bands of bentonite and in some cases, a band of bone separates the coal from the roof whilst in other cases a lense of coal appears between the bone and the true roof. Occasionally the roof is soft and coal may be left for roof support.

It will be obvious, therefore, that the coal as mined may contain considerable amounts of clay impurities deriving not only possibly from the roof and floor of the seam but also from the bentonite bands.

The coal is bright in appearance when it is mined, but on exposure to the air the surfaces quickly assume a dull appearance. The moisture content of the coal is about sixteen per cent and the ash content varies widely. Slacking, as shown by numerous cracks on the surface, also takes place on exposure to the air but this type of coal does not disintegrate easily and with reasonable care in handling the amount of slack is low. There are local areas where the

coal is finer and in some cases rusty, but generally these areas are avoided in mining. The coal appears to contain gray translucent and transparent crystals of selenite or gypsum along its cleavage faces which, whilst not lowering the value of the coal for most purposes, frequently is responsible for a dull gray lustre on the coal blocks when mined.

In the Camrose area there are several coal seams throughout the Edmonton formation(4) containing coals which belong to Group V, that is to say, high volatile subbituminous coals of high moisture and oxygen contents which will not store well. The seam source of the Camrose coal used is not known but the coal was obtained from a strip pit with an overburden of approximately twenty-five feet; the seam was approximately five feet in thickness. The coal was obtained from a fresh stripping section.

In the Nordegg area, the coals belong to the Blairmore-Kootenay formation and are classified as Group I coals, that is to say, low volatile non-coking friable bituminous coals. The seams are found above a band of conglomerate. According to Report #54 of the Research Council of Alberta, there appear to be two principal seams mined, namely No. 2 Seam and No. 3 Seam which are six feet and thirteen feet thick respectively.

The only information available regarding the Luscar coal is that it belongs to Group I.

The coal formation in the Mountain Park area contains high volatile coking bituminous coals, that is to say, the coals fall in Group II. There are at least five seams in this formation but only

two of them are important, each varying in thickness from about twenty-five feet to fifty feet.

Coals from the Crowsnest area fall in Group II. The formation here varies in thickness from five hundred and eighty feet to eight hundred feet and contains at least five seams of which only two are mined at any one place. The International Coal and Coke Company which supplied the Crowsnest coal works only the No. 2 and No. 4 seams. The former seam is approximately fourteen and one half feet thick and the latter nine feet thick.

SECTION I

UPGRADING BY COAL WASHING

Upgrading by Coal Washing

Coal washing consists of the separation of the shaly and other mineral impurities from coals and is dependent upon differences in specific gravity of the two types of material. In practice, though some processes[6][7] operate with solutions or dispersions of the appropriate specific gravity, more generally a similar effect is obtained by either imparting to the mass of water, through which the raw coal undergoing treatment is passing, a rapid upward movement followed by a slow downward movement (the principle of the Jig washer) or causing the water to flow upward at such a velocity that the particles of coal pass upwards with the water whereas the particles of impurity, due to their higher specific gravity, fall against the flow of water (the principle of the upward current classifier). In the former case the coal undergoing treatment is generally supported in its passage through the Jig washer on a screen placed fairly near the surface of the water; in this way the material stratifies and the heavier impurity, forming the lower layer in the stratified mass, can be readily separated from the coal by the provision of a gate placed at a suitable point to separate the stratified mass into clean coal and rejected material. In the upward current classifier, of course, the coal is actually floated off in the upward flowing current of water whilst the shale falling against the current is readily rejected. The methods of separation which apply in these two washers are applied together in such plants as the rheolaver.

In controlling the operation of coal washing plants it is customary to carry out within the laboratory tests which are called washability tests. The coals, being tested, are separated into different fractions by using solutions of suitable and known specific gravities. In order to cover an appropriate range of specific gravity, mixtures of carbon tetrachloride (specific gravity 1.60) and a special petroleum distillate (specific gravity 0.74) or toluene (specific gravity 0.87) are used. The material which has a specific gravity greater than that of the solution used is known as "sinks" and the lighter material which floats is known as "floats". In the divided sample method the "sinks" and "floats" are separately recovered and their weights from a known weight of coal treated are ascertained. In the unit sample method the coal being tested is placed in the solution having the lowest specific gravity, the "floats" are separated while the "sinks" are then treated in the next solution of higher specific gravity and the process repeated until the whole series of treatment is completed. The weights of the fractions obtained from a known weight of sample can be determined. The ash contents of the different fractions, obtained by either method, are then determined. All the tests were carried out by the unit sample method in the Kemp and Thomson Float and Sink Apparatus[8] using mixtures of carbon tetrachloride and a special petroleum distillate.

Many methods have been proposed for the interpretation of float and sink data. Of these, two have been selected, namely those described by R.C. Brewer[8] and B.M. Bird[9][10] respectively. The former method is used to ascertain the feasibility of satisfactory washing the Drumheller slack coal; the latter is especially referred to in discussing the coal washing operations of the Brazeau Cleaning Plant.

Drumheller Slack Coal

A screen analysis was made on the slack coal as obtained from the Midland Coal Company and each fraction thus obtained was used for the washability tests. The data obtained with each separate fraction are given in Table I.

Cumulative data are compiled from the test data. The cumulative value for the ash contents of the "floats" is calculated by using the weights and ash contents of the separate "floats" up to the point in question. Thus: for the fraction larger than 1/2" at a specific gravity of 1.40 there are 78.5 parts of "floats" containing 4.64 per cent ash and 12.4 parts of "floats" containing 12.3 per cent ash or 90.9 parts of "floats" containing $\frac{(78.5 \times 4.64) + (12.4 \times 12.3)}{90.9}$ = 5.68 per cent ash. The cumulative ash in the "sinks" is determined similarly.

To calculate the percentage loss of combustible matter, it is assumed that the total amount of combustible matter in the raw coal fraction larger than 1/2" is 100 - 9.3 = 90.7 parts, 9.3 being the ash content of this fraction. Therefore, at any particular yield, the loss of combustible matter is equal to the total combustible matter in the raw coal less the combustible matter recovered at that yield. In 90.9 parts of "floats", at a specific gravity of 1.40, the combustible matter recovered is $90.9 - (90.9 \times \frac{5.7}{100}) = 85.7$ parts. The loss of combustible matter is therefore 90.7 - 85.7 or 5.0 parts which correspond to 5.5 per cent. Other values are calculated in the same manner.

Table I

Sink and Float Data on Drumheller Slack Coal

Observed Data				Cumulative Data			
Specific Gravity of Material	% Weight of Fraction	% Ash in Sample	Specific Gravity of Solution	% Weight	% Ash in Float	% Ash in Sink	% Loss of Combustible Matter
Fraction Larger than 1/2" - 2.4 per cent of slack coal							
Less than 1.35	78.52	4.64	1.35	78.52	4.64	26.4	17.4
1.35-1.40	12.35	12.30	1.40	90.87	5.68	45.5	5.5
1.40-1.45	1.95	21.07	1.45	92.82	6.00	52.1	2.7
1.45-1.50	1.98	29.86	1.50	94.80	6.50	60.7	2.3
over 1.50	5.20	60.70		100.00	9.31		
Fraction between 1/4" and 1/2" - 41.9 per cent of slack coal							
Less than 1.35	71.63	4.70	1.35	71.63	4.70	31.3	22.2
1.35-1.40	13.83	12.02	1.40	85.46	5.89	49.6	8.4
1.40-1.45	2.71	22.46	1.45	88.17	6.40	55.8	5.9
1.45-1.50	1.42	28.42	1.50	89.59	6.74	59.7	4.8
over 1.50	10.41	59.69		100.00	12.25		
Fraction between 1/8" and 1/4" - 35.4 per cent of slack coal							
Less than 1.35	70.51	4.50	1.35	70.51	4.50	26.9	23.4
1.35-1.40	14.60	11.95	1.40	85.11	5.77	48.2	8.8
1.40-1.45	2.56	21.36	1.45	87.67	6.23	53.8	6.5
1.45-1.50	1.82	26.57	1.50	89.49	6.74	58.5	5.0
over 1.50	10.51	58.54		100.00	12.09		
Fraction smaller than 1/8" - 20.3 per cent of slack coal							
Less than 1.35	43.10	5.22	1.35	43.10	5.22	25.6	51.4
1.35-1.40	21.89	7.38	1.40	64.99	5.96	36.8	26.6
1.40-1.45	8.44	13.28	1.45	73.43	6.80	44.4	17.8
1.45-1.50	3.81	16.92	1.50	77.24	7.30	49.0	14.0
over 1.50	22.76	48.95		100.00	16.78		
Unscreened sample of slack coal*							
Less than 1.35	65.60	4.69	1.35	65.60	4.69	28.9	28.1
1.35-1.40	15.70	10.69	1.40	81.30	5.86	44.1	12.0
1.40-1.45	3.83	16.85	1.45	85.13	6.36	51.1	8.4
1.45-1.50	2.05	23.56	1.50	87.18	6.76	55.5	6.6
over 1.50	12.82	55.53		100.00	13.01		

* All the results for the unscreened sample have been calculated from the results of the different fractions.
All the results have been corrected to a moisture content of 15.0 per cent because the analyses showed that each fraction had a different moisture content.

Figure I

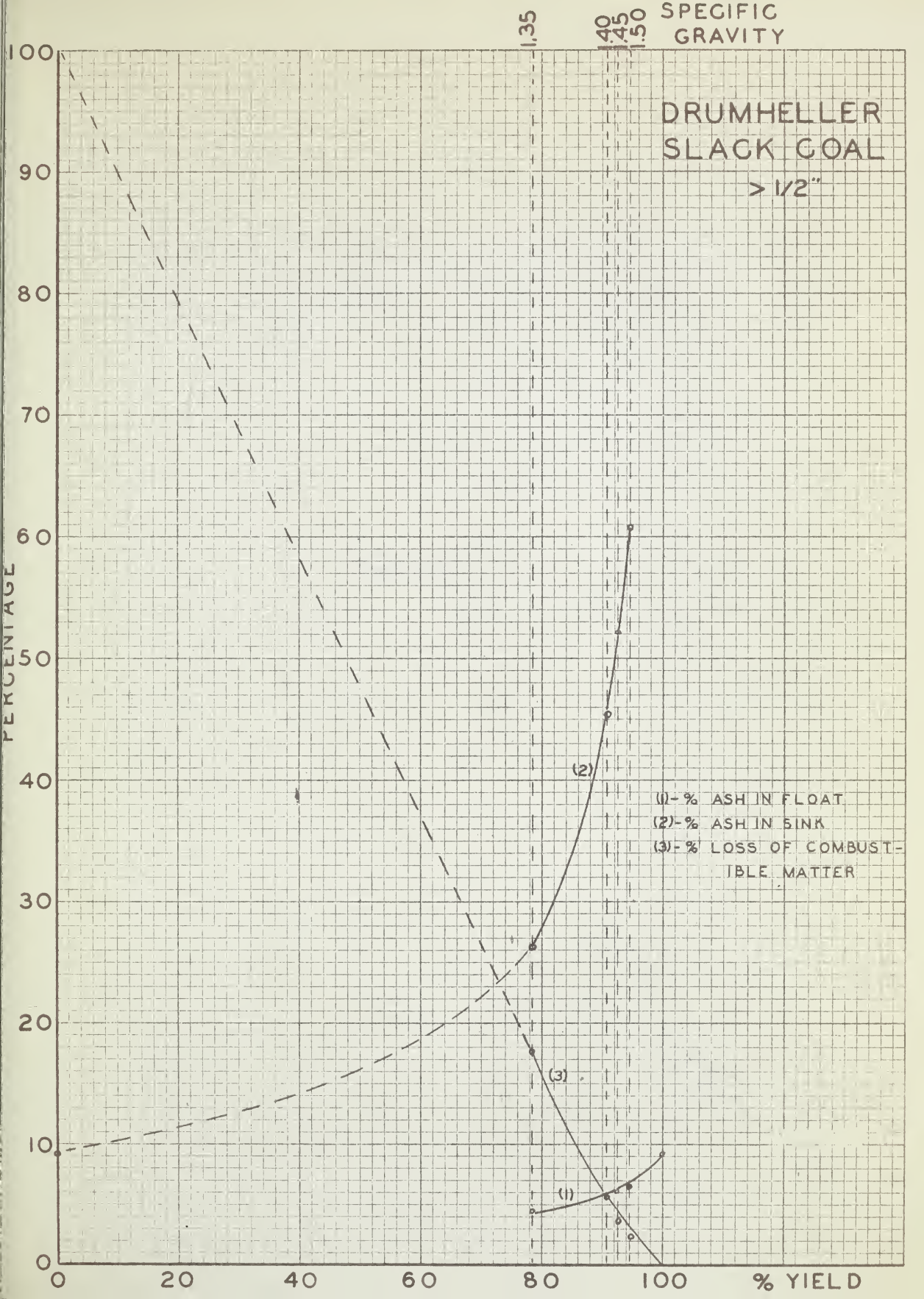

SPECIFIC GRAVITY
1.35
1.40
1.45
1.50
DRUMHELLER SLACK COAL
> 1/2"
PERCENTAGE
% YIELD
(1)- % ASH IN FLOAT
(2)- % ASH IN SINK
(3)- % LOSS OF COMBUSTIBLE MATTER
(1)
(2)
(3)
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100

Figure II

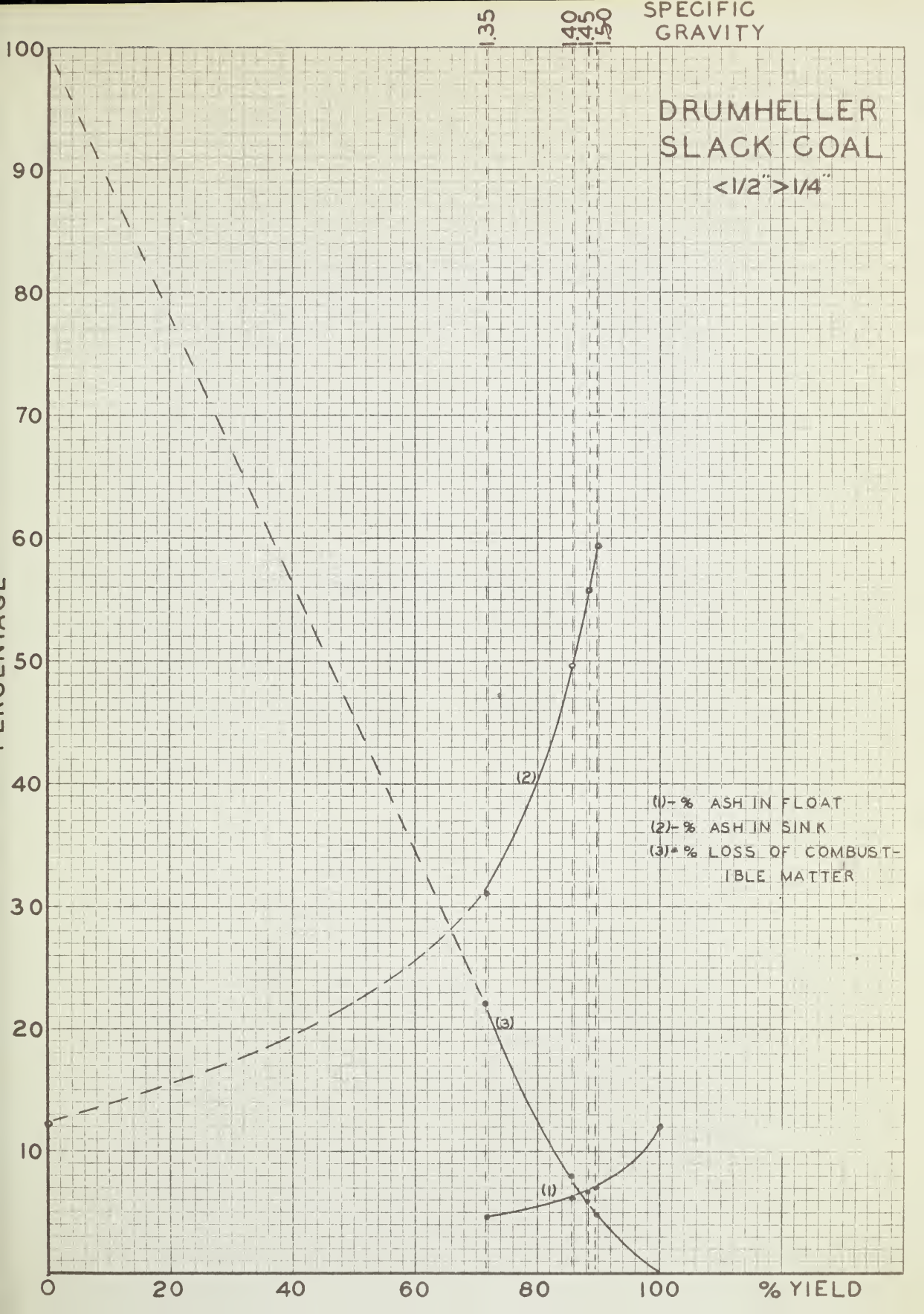

SPECIFIC GRAVITY
1.35
1.40
1.45
1.50
DRUMHELLER SLACK COAL
<1/2" >1/4"
(1)- % ASH IN FLOAT
(2)- % ASH IN SINK
(3)- % LOSS OF COMBUSTIBLE MATTER
(1)
(2)
(3)
PERCENTAGE
% YIELD
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100

Figure III

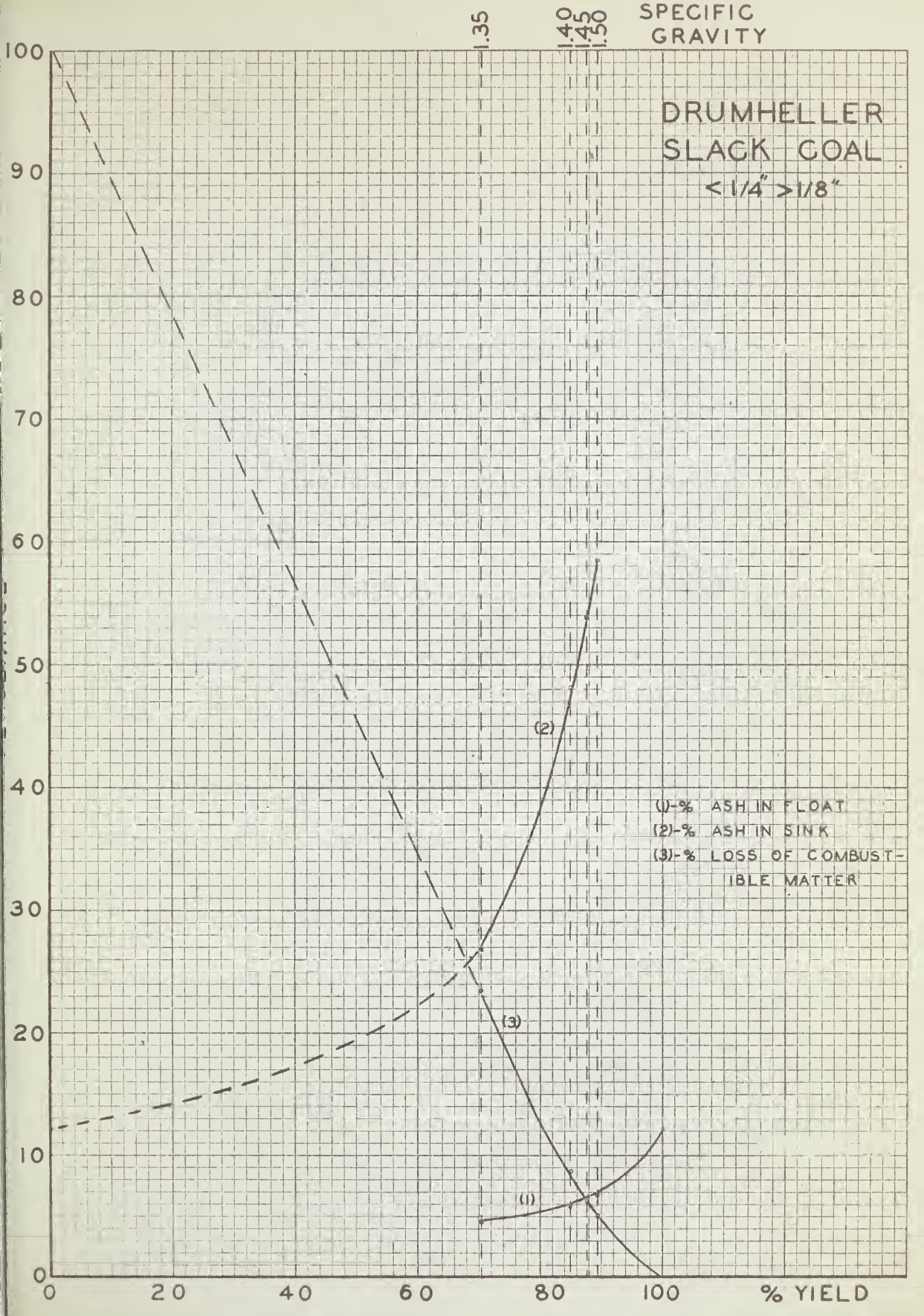

SPECIFIC GRAVITY
1.35
1.40
1.45
1.50
DRUMHELLER SLACK COAL
< 1/4" > 1/8"
(1)-% ASH IN FLOAT
(2)-% ASH IN SINK
(3)-% LOSS OF COMBUSTIBLE MATTER
(1)
(2)
(3)
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
% YIELD

Figure IV

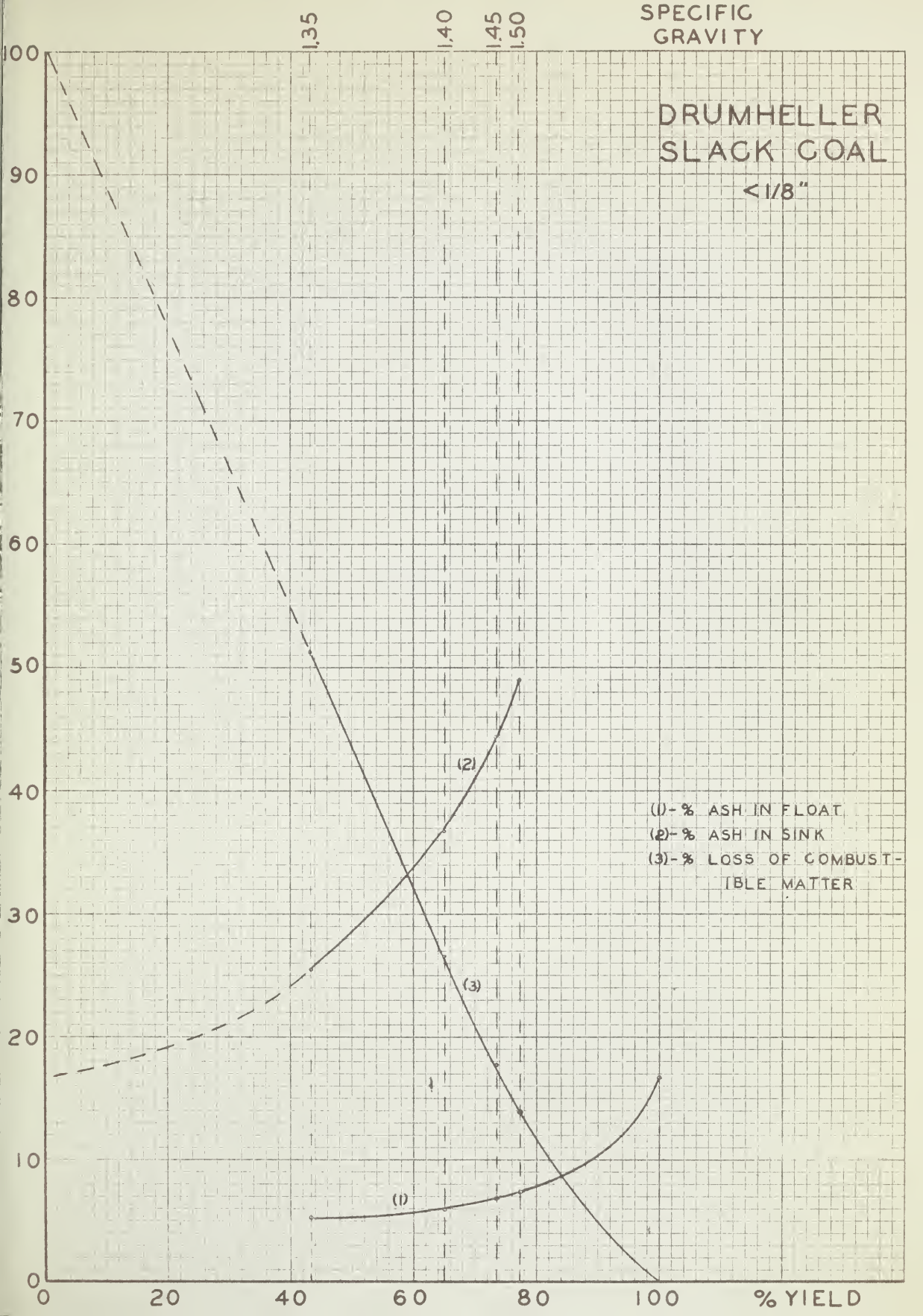
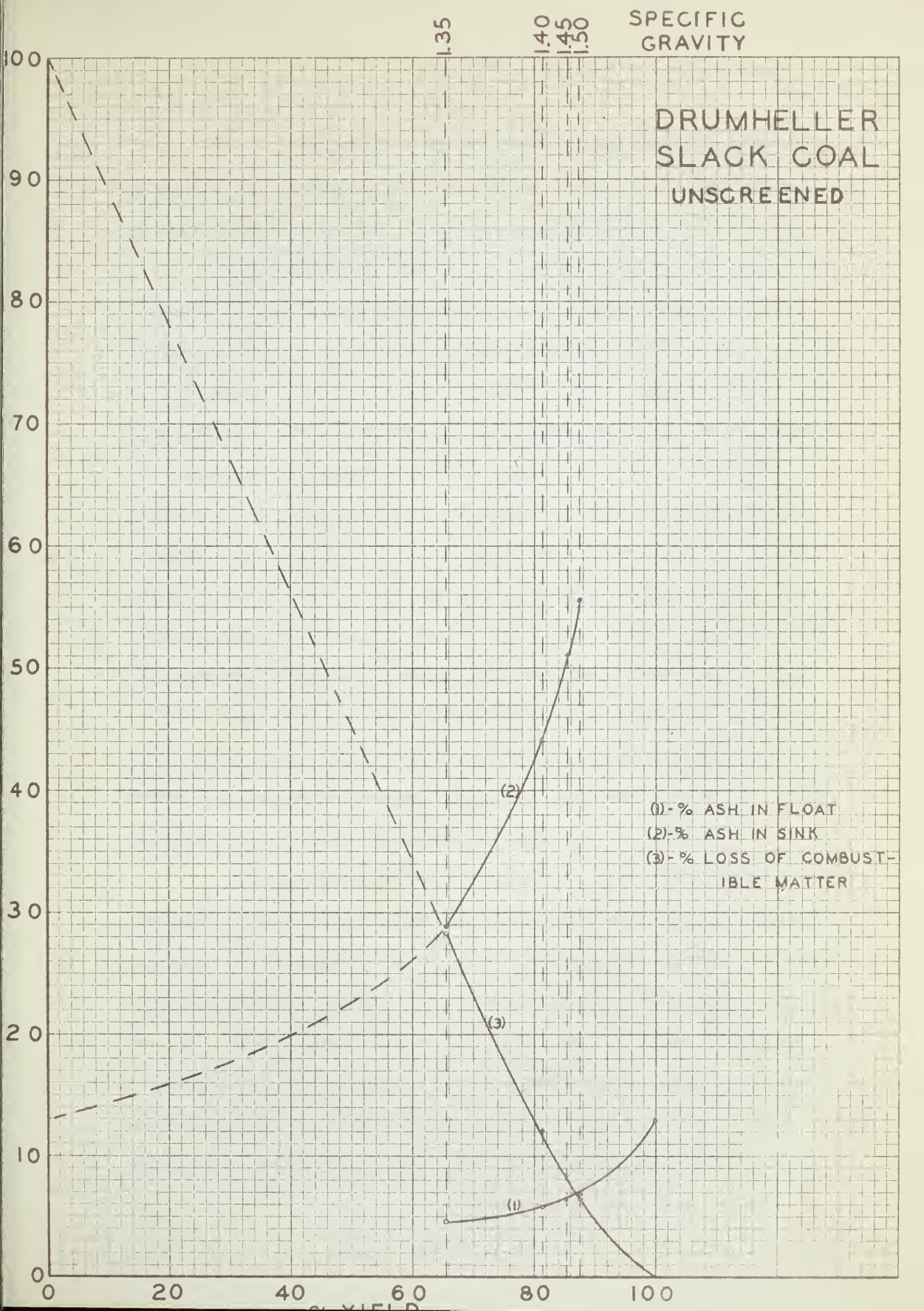

SPECIFIC GRAVITY
1.35
1.40
1.45
1.50
DRUMHELLER SLACK COAL
<1/8"
(1)-% ASH IN FLOAT
(2)-% ASH IN SINK
(3)-% LOSS OF COMBUSTIBLE MATTER
(1)
(2)
(3)
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
% YIELD

Figure V


SPECIFIC GRAVITY
1.35
1.40
1.45
1.50
DRUMHELLER SLACK COAL
UNSCREENED
(1)-% ASH IN FLOAT
(2)-% ASH IN SINK
(3)-% LOSS OF COMBUSTIBLE MATTER
(1)
(2)
(3)
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100

On the "washability curves" constructed from data in Table I (Figures I to V inclusive) the percentage yields, corresponding to each solution employed are indicated by perpendicular dotted lines.

The "washability curves" of the unscreened sample (Figure V) indicate that with efficient operation of a coal cleaning plant it should be possible to obtain a product representing 87 per cent of the coal treated and having an ash content of 6.8 per cent as compared to 13.0 per cent for the raw coal. The separation should correspond with the treatment of a solution of 1.50 specific gravity. Moreover, Figures I-IV inclusive indicate that treating the different sized fractions with a solution of 1.50 specific gravity, reduces the ash content considerably and yet gives a good yield. Economically, the optimum point for the separation of clean coal depends upon the yield of clean coal and its ash content and the loss of relatively clean saleable coal in the rejected material. This point lies somewhere between the points where the ash in the float curve and the loss of combustible matter curve commence to increase, that is to say, in the neighborhood of 85 per cent yield. (Figure V).

The percentage yield indicated between the two dotted "specific gravity" lines shows the amount of material whose specific gravity is between these limits, and therefore the position of these lines is a representation of the specific gravity distribution of the coal. Where these gravity lines are close together, favorable cleaning possibilities are indicated because of the small amount of material having a specific gravity approximately the same as that used for the separation. In all five cases, the gravity lines 1.45

and 1.50 lie close together which confirms the above conclusion regarding the point of separation.

The Brazeau Cleaning Plant

The run of mine coal, a mixture from the No. 2 and No. 3 seams in the Nordegg district (page 6), is fed to the screens of the cleaning plant where it is divided into 3 fractions, namely: coal below 1/4", coal between 1/4" and 3/4", and coal larger than 3/4". The fraction below 1/4", i.e. the dust and fine coal, which has an ash content of approximately 16% is not cleaned at all but goes directly to storage for briquetting. The fraction between 1/4" and 3/4" is cleaned on air-tables and the cleaned product then passes directly to the briquetting plant. Coal larger than 3/4" is cleaned in a Vissac Jig, dried and sold.

(a) Fraction 1/4" to 3/4" - Treatment on Air-Tables

Composite samples of the raw coal fed to the air-tables and of the cleaned coal and the refuse were obtained and washability tests carried out on all three samples. All the observed and calculated data for this series are contained in Table II.

The method used for the interpretation of the sink and float data is that described by B.M. Bird in Report of Investigations #3012 United States Department of Interior, Bureau of Mines. In this method the percentage "float" is plotted against the percentage cumulative ash, the percentage elementary ash and the specific gravity of the solutions used respectively. The elementary ash is the ash content of the highest-ash particle included in a "float" fraction at any given cumulative weight percentage. The two methods for interpreting

float and sink data have been used in this thesis to illustrate the point that the choice of method used for interpretation depends upon the information desired.

The cumulative ash curve and the elementary ash curve are calculated from the test data. The elementary ash curve shows the rate of change of the ash content at different yields but it must be pointed out that this is only a convenient approximation and not a mathematically exact method.

The calculation of the elementary ash curve is based on the assumption that all the float particles are arranged in order of increasing ash content. It is obvious that every particle of the run-of-mine coal fed to the air-table which has a specific gravity less than 1.35 does not contain exactly 3.5 per cent ash, that is to say, the ash content of the floated material. Since the average ash content of all the particles included in the range from 0.0 to 39.5 per cent cumulative weight is 3.6 per cent, all those particles below 19.75 per cent cumulative weight contain less than 3.6 per cent ash and all those above contain more than 3.6 per cent ash. Thus a particle at 19.75 per cent cumulative weight should contain 3.6 per cent ash which is the first point on the curve. Table II shows that a particle having a specific gravity of exactly 1.40 is at a point 10.5 per cent higher than a particle with a specific gravity of 1.35 or at the cumulative weight of 50.0 per cent. The particles in this fraction have an average ash content of 7.5 per cent and the cumulative weight per cent corresponding to 7.5 per cent elementary ash is $39.5 + \frac{10.5}{2} = 44.7$ which gives us the second point on the curve. A rule for determining

Table 2

Sample	Specific Gravity of Material	% Wt. of Fraction	% Ash in Sample	Specific Gravity of Solution	% Cumulative Weight	% Cumulative Ash
Coal feed to air-tables	Less than 1.35	39.5	3.63	1.35	39.5	3.63
	1.35-1.40	10.5	7.45	1.40	50.0	4.42
	1.40-1.45	10.1	12.33	1.45	60.1	5.74
	1.45-1.50	8.5	18.38	1.50	68.6	7.30
	1.50-1.56	8.3	24.37	1.56	76.9	9.15
	over 1.56	23.1	49.85		100.0	18.54
Cleaned coal from air-table	Less than 1.35	49.6	3.65	1.35	49.6	3.65
	1.35-1.40	8.7	7.43	1.40	58.3	4.18
	1.40-1.45	8.9	12.23	1.45	67.2	5.25
	1.45-1.50	9.4	17.92	1.50	76.6	6.80
	1.50-1.56	8.5	24.08	1.56	85.1	8.53
	over 1.56	14.9	42.51		100.0	13.59
Refuse from air-table	Less than 1.35	3.6	4.14	1.35	3.6	4.14
	1.35-1.40	1.1	7.92	1.40	4.7	5.11
	1.40-1.45	3.4	12.31	1.45	8.1	8.15
	1.45-1.50	2.3	19.55	1.50	10.4	10.67
	1.50-1.56	5.1	25.13	1.56	15.5	15.42
	over 1.56	84.5	64.49		100.0	56.89

Note: All results have been corrected to a moisture content of 1.2% because such fraction had a different moisture content when analyzed.

points on the elementary ash curve from sink and float data may be expressed as:

> "One half of the "weight per cent" of the specific-gravity interval involved, plus the "cumulative weight, per cent" of all material of lower specific gravity, is plotted against the ash content (not cumulative ash) of the specific gravity interval involved."(10)

From Figure VI, it can be seen that with 100 per cent efficiency it might be possible to obtain a product representing 77 per cent of the feed and having an ash content of 9.7 per cent as compared to 18.2 per cent for the feed, if cleaning were done to an equivalent specific gravity of 1.56. This product would contain no pieces of coal with an ash content exceeding 30 per cent (elementary ash curve). With no two yields for successive gravity solutions close together, the results indicate that a clean separation at any specific gravity is not practical.

Figure VII shows the results of the tests on the cleaned coal. Large scale cleaning cannot be 100 per cent efficient and the equivalent specific gravity of the table setting is not known; but nearly 15 per cent of this product had a gravity above 1.56 and an ash content of 43 per cent.

Figure VIII illustrates the results obtained on the refuse which contained approximately 15 per cent with a gravity lighter than 1.56.

Figures VII and VIII confirm the above conclusion regarding the difficulty in obtaining a sharp separation.

Figure VI

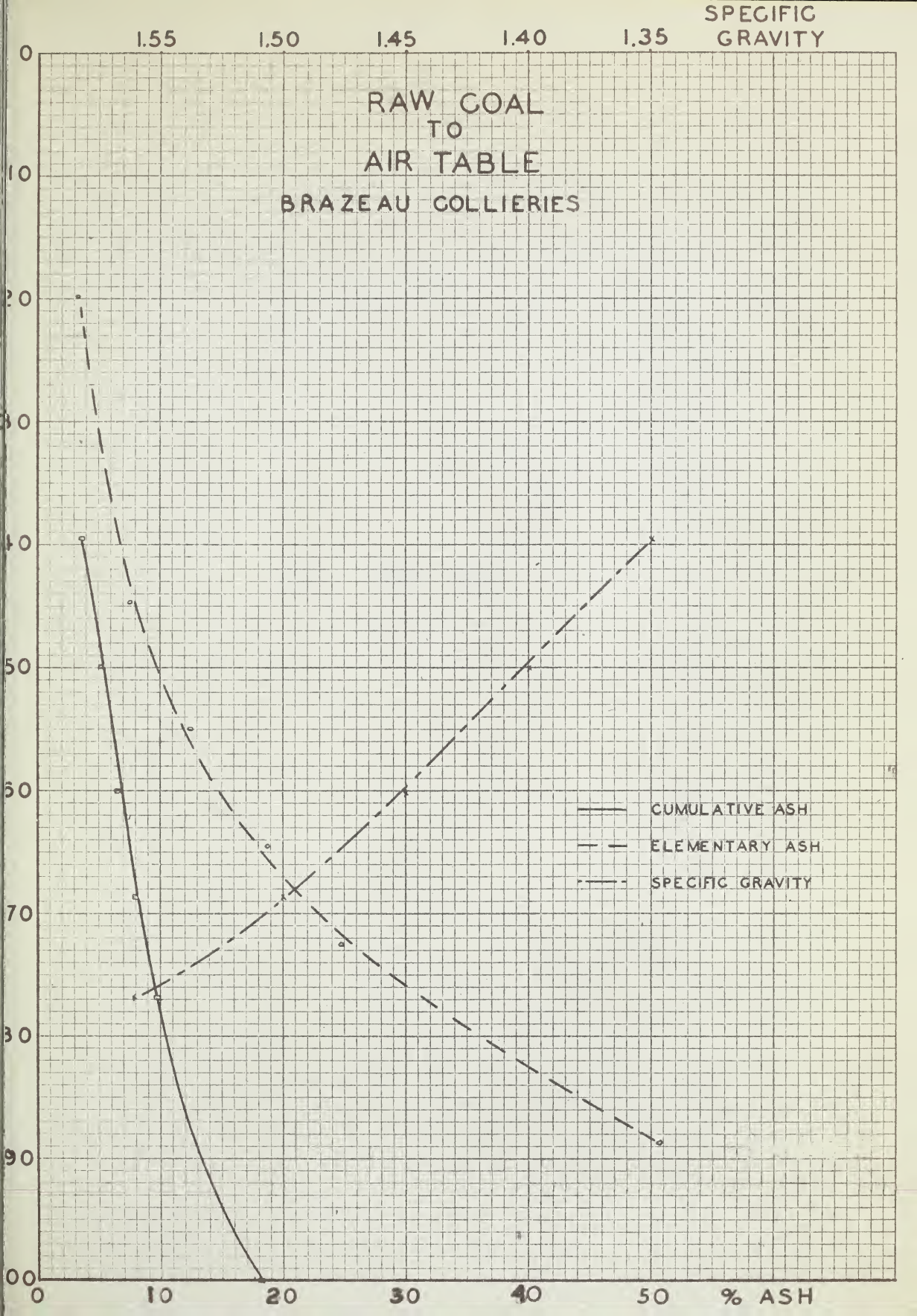

SPECIFIC GRAVITY
1.55
1.50
1.45
1.40
1.35
RAW COAL
TO
AIR TABLE
BRAZEAU COLLIERIES
CUMULATIVE ASH
ELEMENTARY ASH
SPECIFIC GRAVITY
0
10
20
30
40
50
% ASH

Figure VII

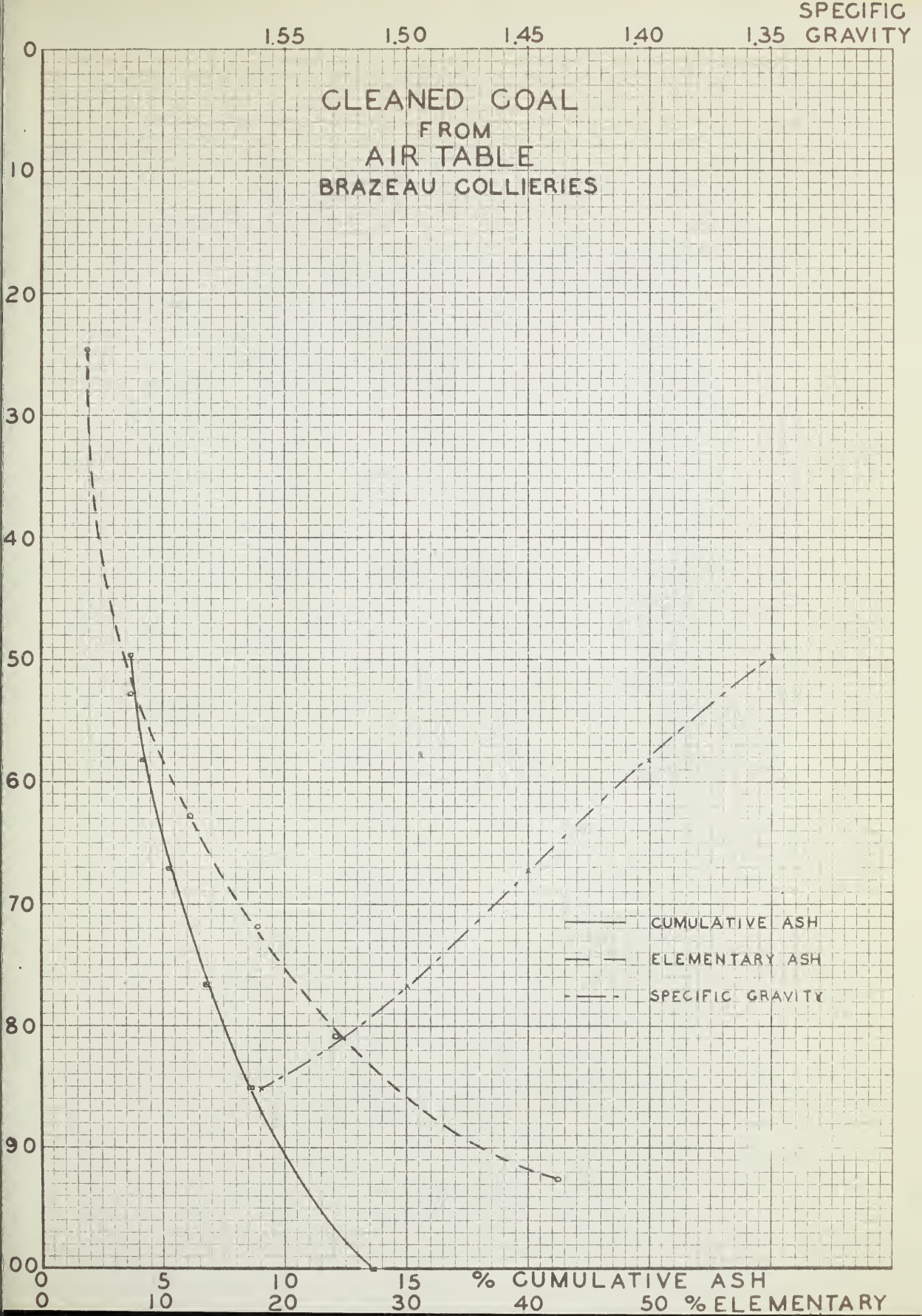
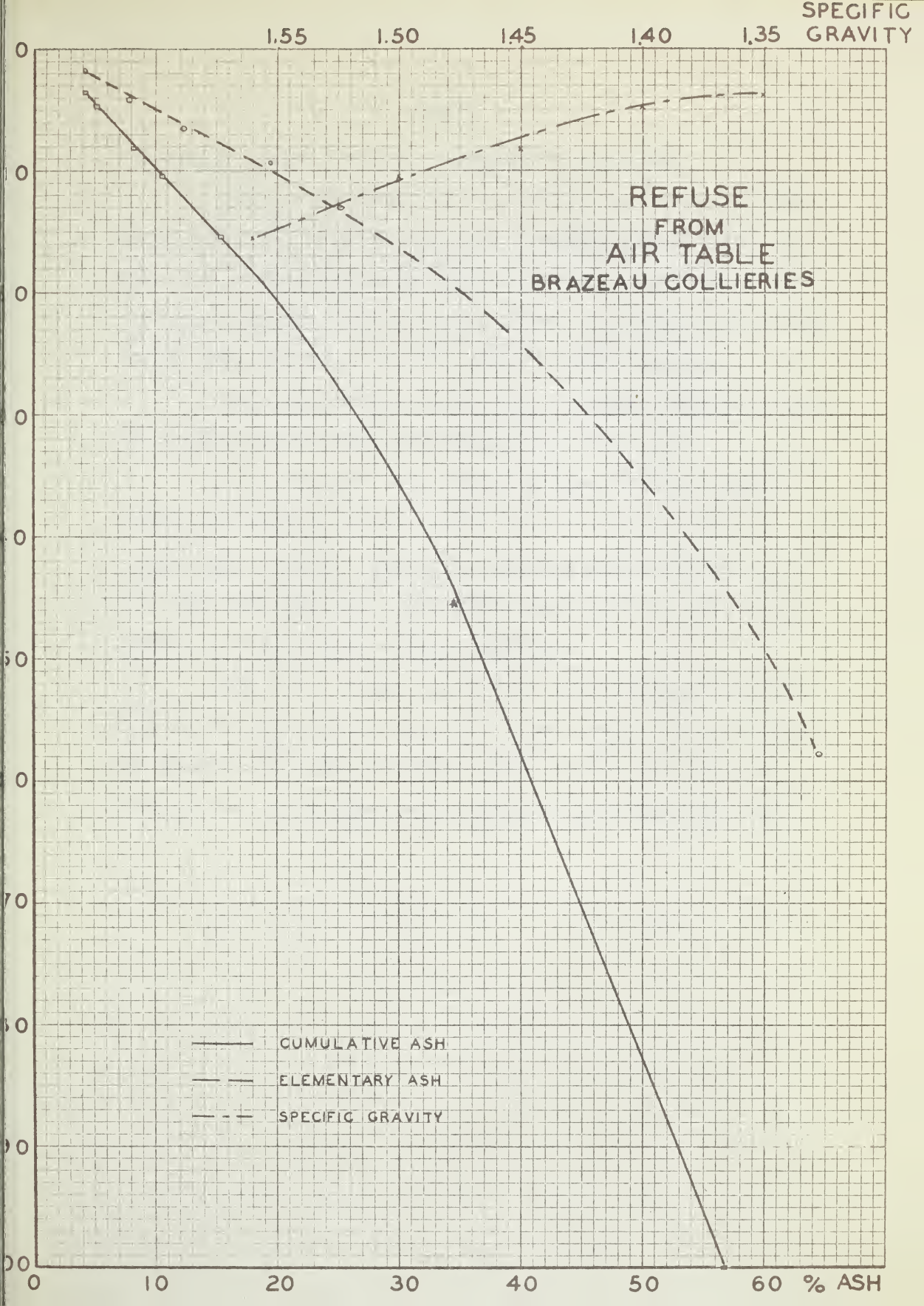

SPECIFIC GRAVITY
1.55
1.50
1.45
1.40
1.35
CLEANED COAL
FROM
AIR TABLE
BRAZEAU COLLIERIES
0
10
20
30
40
50
60
70
80
90
00
CUMULATIVE ASH
ELEMENTARY ASH
SPECIFIC GRAVITY
0
5
10
15
% CUMULATIVE ASH
0
10
20
30
40
50 % ELEMENTARY

Figure VIII


SPECIFIC GRAVITY
1.55
1.50
1.45
1.40
1.35
REFUSE
FROM
AIR TABLE
BRAZEAU COLLIERIES
CUMULATIVE ASH
ELEMENTARY ASH
SPECIFIC GRAVITY
0
10
20
30
40
50
60
% ASH

(b) Fraction Larger than 3/4" - Treatment in Vissac Jig

Although the Vissac Jig was installed to handle only coal larger than 3/4", in actual operation it handles a small amount of finer coal because some of the lumps, too large to pass through even the largest opening in the vibrating screen, are subsequently crushed, and all this coal goes to the jig without further screening.

Table III contains all the data for samples of the raw coal, the cleaned coal and the refuse leaving the Vissac Jig.

As in the former case, Figure IX shows that the specific gravity distribution for this coal is such as to make economical washing impracticable. Working to a specific gravity of 1.56 in this case would only give a theoretical yield of 63 per cent which appears to be too low for economic operation.

The results of the examinations of the separated fractions from the Jig show that the separation is not sharp; 18.5 per cent of the cleaned product had a specific gravity greater than 1.56 and 13.5 per cent of the refuse had a specific gravity less than 1.50.

Table 3

Sample	Specific Gravity of Material	% Weight of Fraction	% Ash in Sample	Specific Gravity of Solution	% Cumulative Weight	% Cumulative Ash
Coal feed to Vissac Jig	Less than 1.35	43.4	4.30	1.35	43.4	4.30
	1.35-1.40	3.2	9.42	1.40	46.6	4.66
	1.40-1.45	6.3	12.72	1.45	52.9	5.62
	1.45-1.50	2.9	19.58	1.50	55.8	6.34
	1.50-1.56	7.5	23.17	1.56	63.3	8.34
	over 1.56	36.7	64.43		100.0	28.93
Cleaned coal from Vissac Jig	Less than 1.35	55.8	4.43	1.35	55.8	4.43
	1.35-1.40	7.0	9.14	1.40	62.8	4.94
	1.40-1.45	8.7	15.10	1.45	71.5	6.17
	1.45-1.50	5.5	19.17	1.50	77.0	7.09
	1.50-1.56	4.5	24.62	1.56	81.5	8.06
	over 1.56	18.5	47.14		100.0	15.29
Refuse from Vissac Jig	Less than 1.35	7.8	5.81	1.35	7.8	5.81
	1.35-1.40	1.2	19.21	1.40	9.0	7.56
	1.40-1.45	2.0	22.06	1.45	11.0	10.18
	1.45-1.50	2.5	22.73	1.50	13.5	12.52
	1.50-1.56	6.5	27.81	1.56	20.0	17.50
	over 1.56	80.0	66.54		100.0	56.74

Note: All the results have been corrected to a moisture content of 1.2% because each fraction had a different moisture content when analyzed.

Figure IX

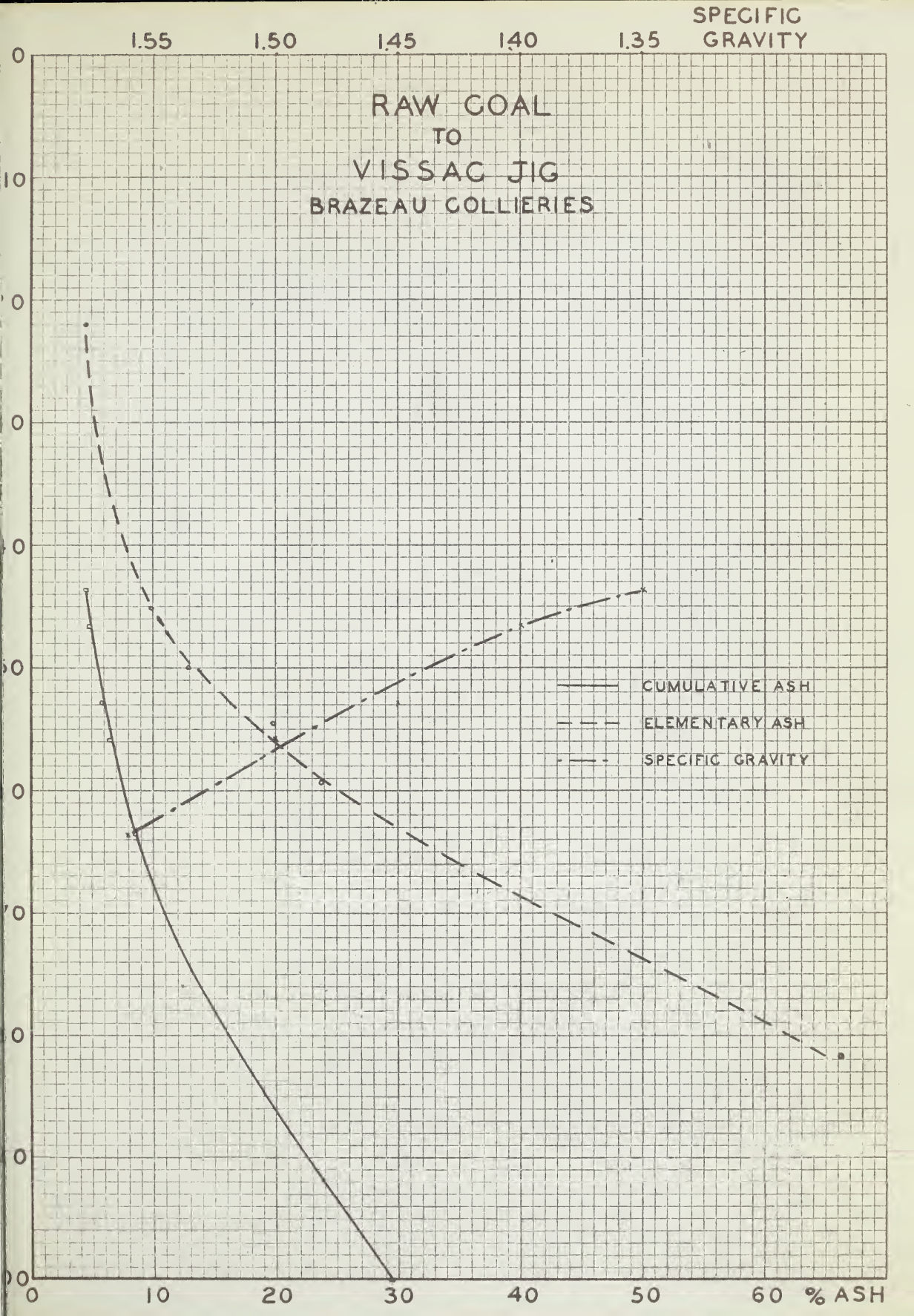

SPECIFIC GRAVITY
1.55
1.50
1.45
1.40
1.35
RAW COAL
TO
VISSAC JIG
BRAZEAU COLLIERIES
CUMULATIVE ASH
ELEMENTARY ASH
SPECIFIC GRAVITY
0
10
20
30
40
50
60
% ASH

Figure X

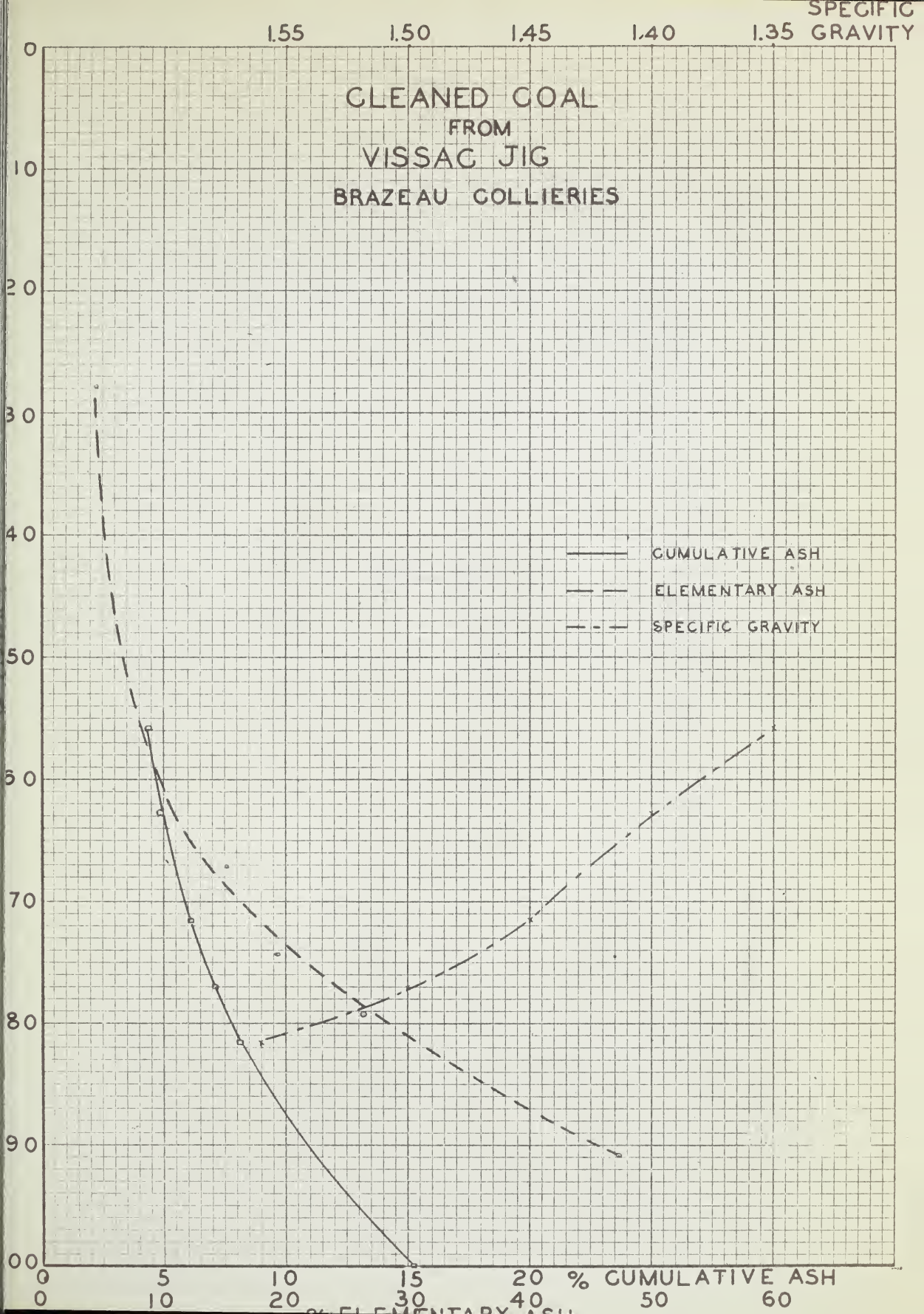
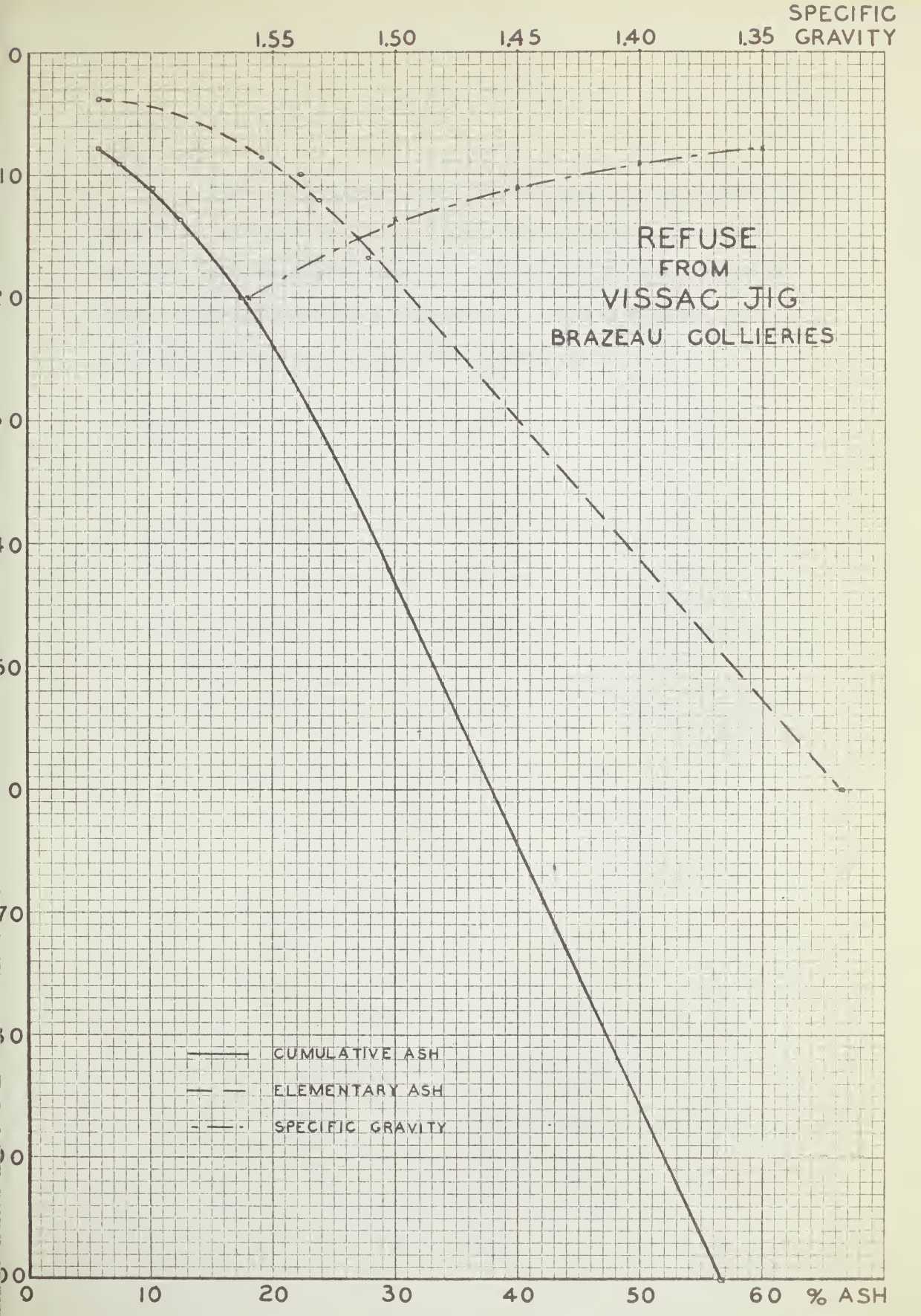

SPECIFIC GRAVITY
1.55
1.50
1.45
1.40
1.35
CLEANED COAL
FROM
VISSAC JIG
BRAZEAU COLLIERIES
CUMULATIVE ASH
ELEMENTARY ASH
SPECIFIC GRAVITY
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
% CUMULATIVE ASH
0
10
20
30
40
50
60
% ELEMENTARY ASH

Figure XI


SPECIFIC GRAVITY
1.55
1.50
1.45
1.40
1.35
REFUSE
FROM
VISSAC JIG
BRAZEAU COLLIERIES
CUMULATIVE ASH
ELEMENTARY ASH
SPECIFIC GRAVITY
0
10
20
30
40
50
60
% ASH

Conclusion

Since no two coals are alike, differing in the nature and amount of removable and non-removable mineral matter, every coal presents its own cleaning problem. The washability tests indicate that a good separation of clean coal and refuse is possible with Drumheller slack coal but not with Nordegg coal.

SECTION 2

BRIQUETTING WITH A SUITABLE BINDING AGENT

Briquetting with a Suitable Binding Agent

Briquetting is recognized as a practicable method of converting much of what is now considered unusable fuel, because of its fineness of division, into a clean lump fuel for domestic and industrial purposes. Briquetting consists of mixing with graded coal a suitable amount of binder, either in a crushed or molten condition, heating the mass and then pressing it into briquettes.

Figures XII and XIII, showing the yearly production of briquettes in Alberta and the United States respectively, indicate the rapid expansion which has taken place in the briquetting industry since about 1939.

Some of the important factors in briquetting may be summarized as follows:

(a) The slack coal should be as clean as possible. A high ash content requires a greater percentage of binder, because the binder does not adhere well to slate or to other similar high ash materials.

(b) The binder should be well dispersed so that all the voids of the finely divided coal are more or less completely filled in. A minimum quantity of asphaltic binder in a proper compounded mixture produces a strong weatherproof briquette.

(c) The briquettes should satisfy the following requirements:

(1) they should be of maximum density

(2) they should be strong enough to withstand handling and transportation

Figure XII

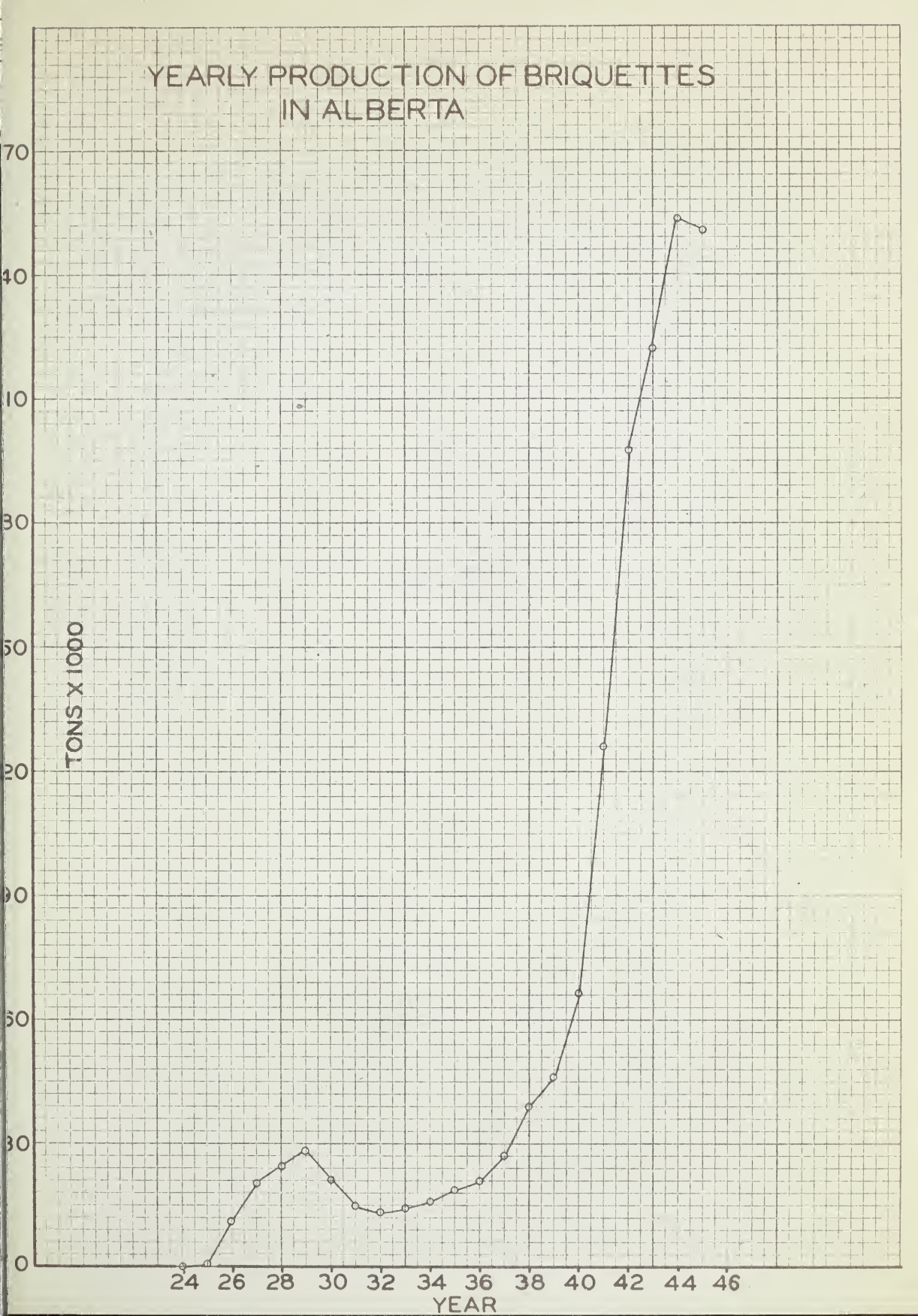
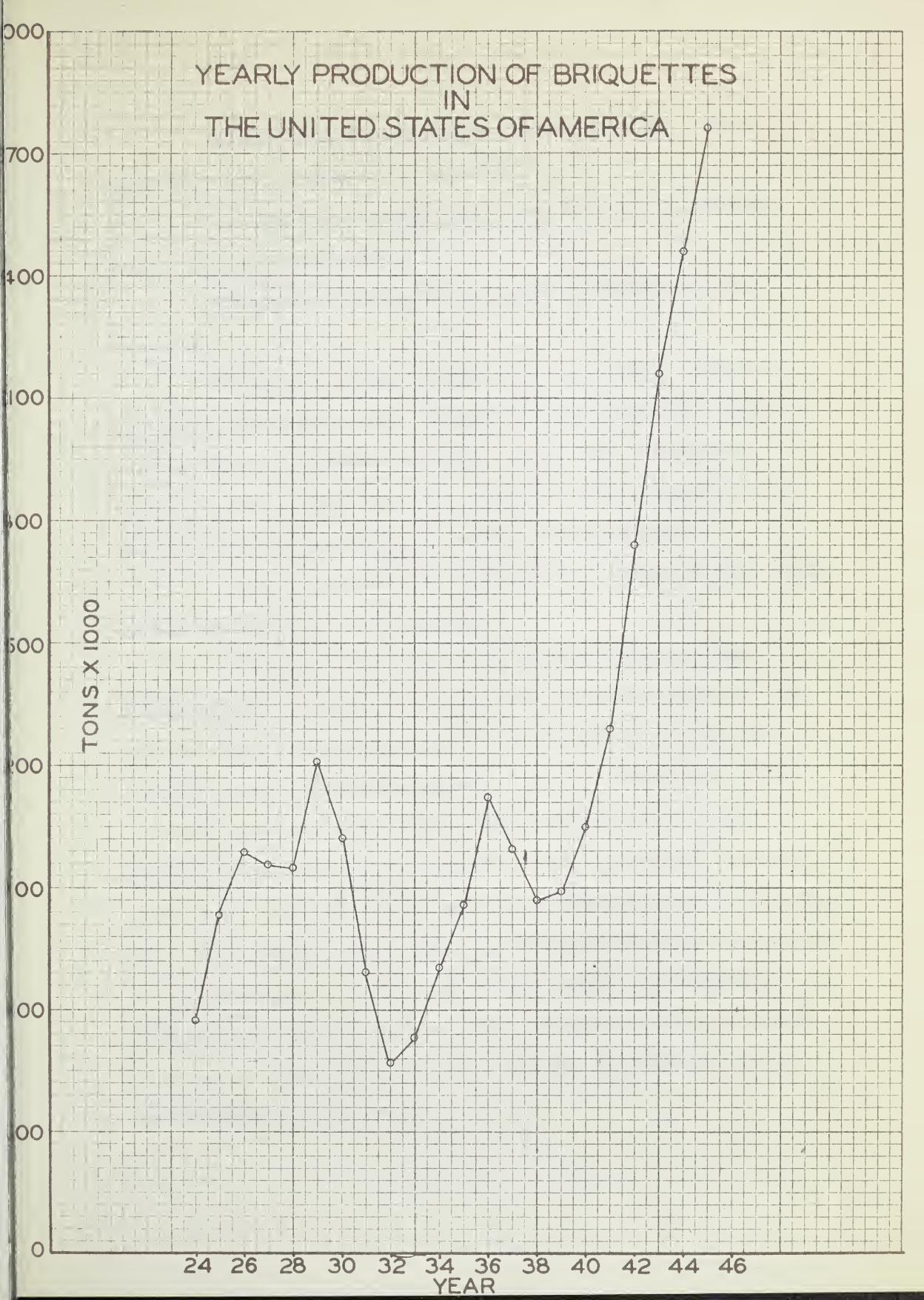

YEARLY PRODUCTION OF BRIQUETTES
IN ALBERTA
TONS X 1000
70
40
10
30
50
20
90
50
30
0
24 26 28 30 32 34 36 38 40 42 44 46
YEAR

Figure XIII


YEARLY PRODUCTION OF BRIQUETTES
IN
THE UNITED STATES OF AMERICA
TONS X 1000
000
700
400
100
600
500
200
00
00
00
0
24 26 28 30 32 34 36 38 40 42 44 46
YEAR

(3) they should be smooth and regular in shape. Sharp edges are readily broken off in handling.

(4) they should retain their shape and not disintegrate during storage or combustion

(5) the heat value of the original coal should not be decreased

(6) the ash content should not be increased. Inorganic binders of high mineral matter content such as lime, clay, sulfur, calcium chloride, magnesium chloride, cement, etc. increase the mineral content of the briquettes without suitable compensation for the increased ash by providing a better or cheaper binder.

(7) all the desirable characteristics of the raw coal should at least be retained if not enhanced.

A "binder" as referred to in coal briquetting is any substance which is capable of binding fine materials to one another and which does not interfere with the attainment of any desirable physical properties in the briquette. A special petroleum asphalt is used more extensively than any other binding medium in coal briquetting in America. This asphalt, which is tough and hard when cold and yet possesses the properties of adhesiveness and stickiness, has a low viscosity and is almost as fluid as water when heated above its softening point. For all the studies made on some phases of briquetting, which are described later, a special petroleum asphalt or briquette binder was supplied by Imperial Oil Company. It had the following specifications:

Softening Point 150-152°

Penetration

at 32°F. not less than 2 mm.

at 77°F. 10-30 mm.

at 115°F. not more than 150 mm.

Effect of Pressure on the Density of Briquettes

As a preliminary measure in order to permit experiments to be made with relatively small amounts of coal and to increase the number of experiments which could be made in a limited time a small briquetting mould was designed, as illustrated in Figure XIV. The different parts of the mould indicated on this figure are described below:

The base of shaft (A) was 3 3/4" diameter and 1" thick. A hole 2" diameter and 3/8" deep was cut to hold the shaft.

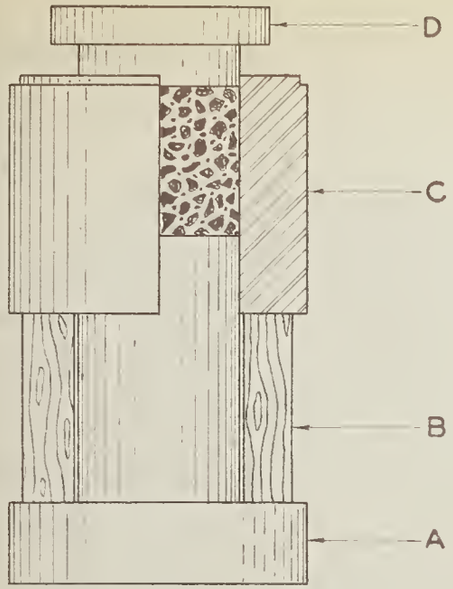
The shaft was 2" diameter and 3 3/4" long.

A block of wood (B) 2 3/8" in length was used to support the collar (C) until the briquetting mixture had been placed in the mould and pressure applied in the hydraulic press.

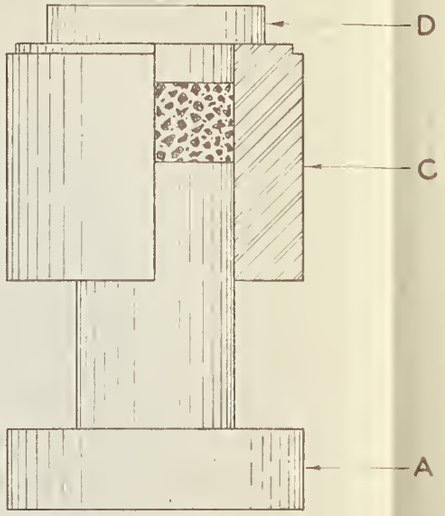
The collar (C) was 3 3/4" outside diameter, 2" inside diameter and 3" long. A section 1/8" by 1/8" was cut away on the outside circumference at one end which was used to centre the loose collar (E) over the shaft.

The cap (D) had an overall length of 1", 1/2" length had a diameter of 2" and the other 1/2" length a diameter of 2 3/4".

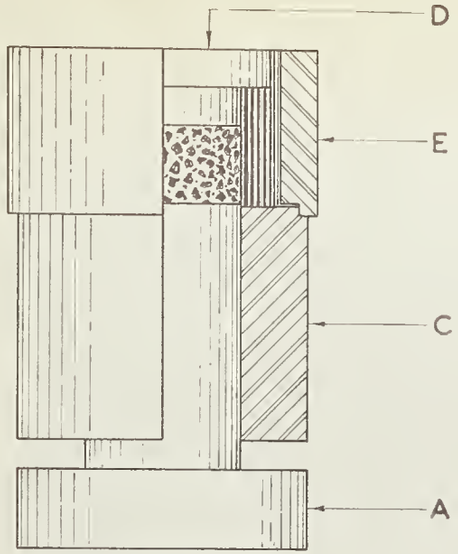
The loose collar (E) was 4" outside diameter, 3" inside diameter and 2 1/8" long. A section 1/8" x 1/4" was cut away on the



SECTION I

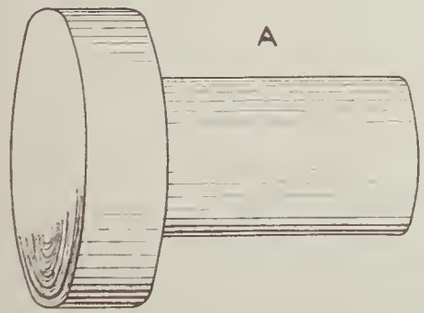


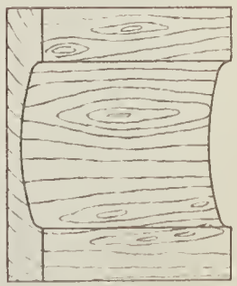
SECTION 2

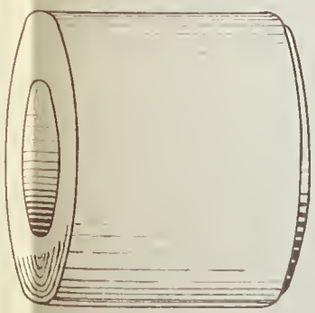


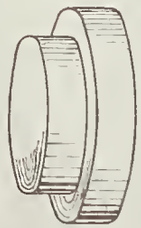
SECTION 3

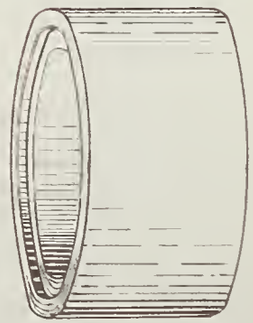
BRIQUETTE











BRIQUETTE MOULD.

Drawn by S.J. Groot Feb 5th

inside circumference at one end to centre this loose collar over the shaft. This part was used only when extruding the briquette from the mould.

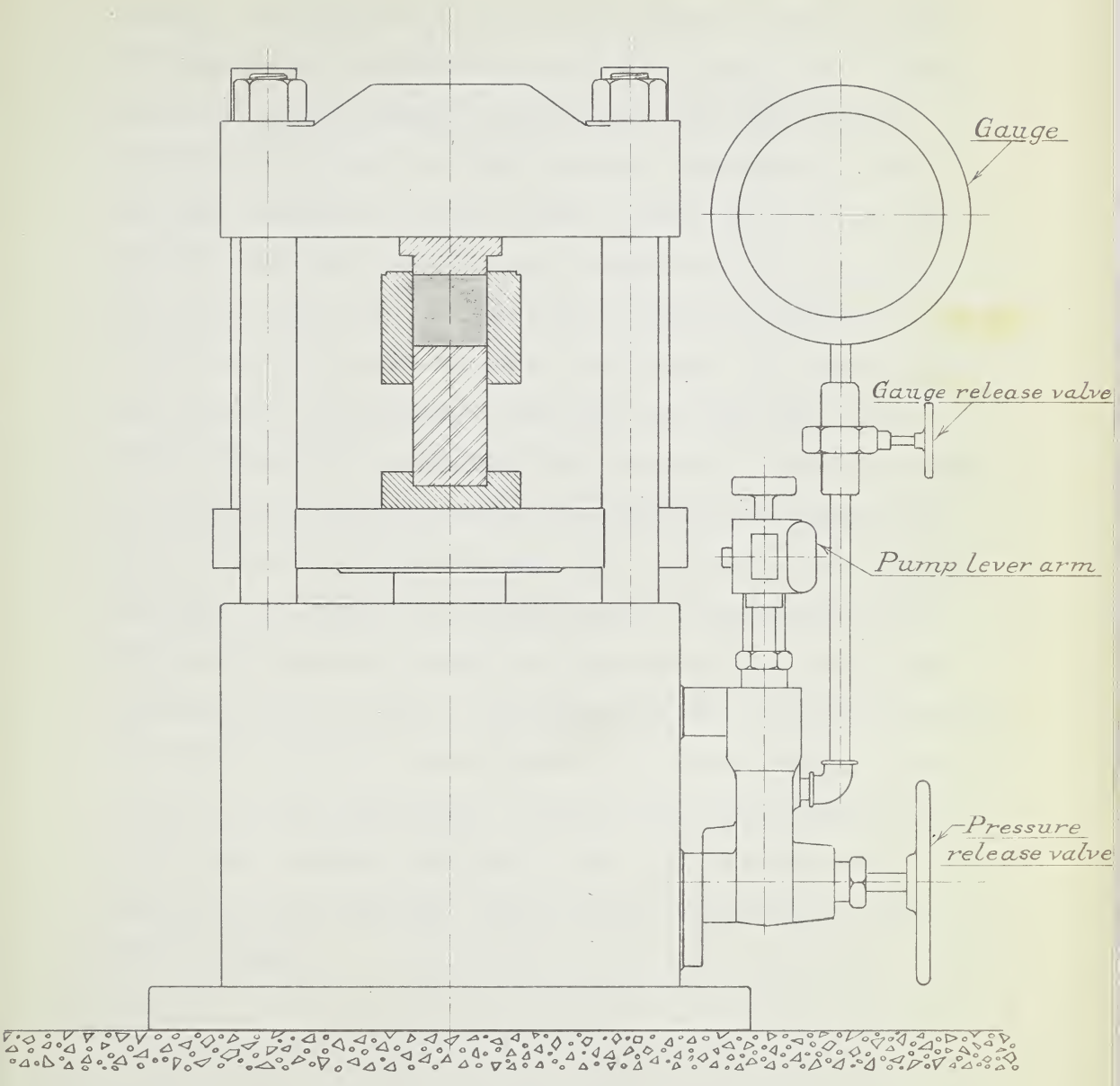
The base (A), the collar (C) and the loose collar (E) were made from cold rolled steel whilst the shaft (A) and the cap (D) were made from a special tool steel. Sections 1, 2, and 3, respectively show the relative positions of the above parts when the briquetting mixture has been placed in the mould prior to pressing, after the pressure has been applied, and after the briquette has been extruded from the mould.

Pressure was applied to the briquette mixture in the mould by means of a 30 ton "Watson Stillman" Hydraulic Press. This is shown in Figure XV.

Since the experiments described previously had shown that a good separation of clean coal and refuse material was possible with Drumheller slack coal, the coal used for these investigations was washed by treatment on a shaker screen available in the University Mining Department. It consists of two screens, one set below and in front of the other. The screens are set at a low angle and the material being screened moves down the screen owing to the forword thrust imparted to the screens by means of two cams located on the single driving shaft. The washing was accomplished by subjecting the slack coal, as it moved down the two screens, to a fine jet of water. The water passing through the screens carried the fine particles of dirt.

The first batch of briquettes was made from a mixture containing 80 per cent Drumheller slack which had been so washed and

Figure XV



HYDRAULIC PRESS WITH BRIQUETTE MOULD FORMING CYLINDRICAL BRIQUETTE.

Drawn by S J Groot

air-dried, 20 per cent Crowsnest coking coal and 6 mixing ratio of asphalt. The mixing ratio represents the number of parts by weight of asphalt which are added to 100 parts of the mixed coals. The two coals were mixed and heated for five minutes in a steam-jacketed helical mixer or until the mixture reached a temperature of 125°C. The mixer consists of a helical vessel in which there are two blades geared so that one rotates at twice the speed and in the opposite direction to the other. The mixer can be tipped to discharge its contents and has a maximum capacity of 25 pounds. The asphalt which had been weighed and heated to over 200°C. was then added and the mixing continued for an additional five minutes. In order to maintain the mixture in a plastic condition only sufficient was withdrawn at one time to make a single briquette. This amounted to about 60 grams by weight. The pressure was applied rapidly to the mixture in the mould until the desired pressure was attained and this pressure was maintained for two minutes. The pressure was then immediately released. The extruded briquettes were allowed to cool and the density of each briquette was then determined. A briquette was weighed first in the air and then completely submerged in water. The densities were calculated in the usual way. Table IV shows the results for this series of tests.

Table IV

Effect of Pressure on the Density of Briquettes

Dial Reading	Pressure p.s.i.	Density	Dial Reading	Pressure p.s.i.	Density
400	1260	1.05	2000	6280	1.10
600	1890	1.06	2200	6910	1.10
800	2520	1.08	2400	7540	1.11
1000	3150	1.09	2600	8160	1.12
1200	3780	1.09	2800	8790	1.11
1400	4400	1.10	3000	9420	1.12
1600	5030	1.10	3200	10050	1.12
1800	5660	1.10			

Since eight kilograms of this mixture had been made, part of it was compressed on the two large presses already installed by the Research Council. Density determinations were also made on the briquettes obtained in this way. A figure of 1.06 was obtained for the briquettes from the plunger press and 1.09 for the briquettes from the roll press.

The second batch of briquettes was made from a mixture consisting of 67 per cent Drumheller slack, which had been washed and air dried, 33 per cent coking coal and 8 mixing ratio of asphalt. The results obtained on this batch of briquettes are given in Table V.

Table V

Effect of Pressure on Density of Briquettes

Dial Reading	Pressure P.s.i.	Density	Dial Reading	Pressure p.s.i.	Density
200	630	1.07	1800	5660	1.14
600	1890	1.10	2200	6910	1.15
1000	3150	1.12	2600	8160	1.14
1400	4400	1.13	3000	9420	1.15

The results in Tables IV and V show that the density of the briquettes increases with pressure up to a pressure of approximately 4000 p.s.i. but that above 4000 p.s.i. pressure does not affect the density of the briquette to any appreciable extent.

The Effect of the Amount of Binder Used on the Strength of Briquettes

Seventeen and one-half pounds (8 kilograms) of coal were placed in the steam-jacketed helical mixer and heated for seven minutes, whereby the coal temperature was raised to a recorded temperature of approximately 125°C. The weighed amount of binder was heated separately to over 200°C. so that it would pour and mix readily, and it was then poured onto the coal in the mixer. The temperature of the binder was recorded. Mixing of coal and binder continued for three minutes, when the temperature of the mix was measured and also recorded. Water, in the proportion of 8 parts to 100 parts by weight of coal was then added in order to reduce the temperature to that suitable for pressing, and in order to make a mix that would briquette without sticking to the rolls. Mixing was continued for another 30 seconds.

Industrially, steam is passed directly into the mass in the mixer, and the mass is not heated to as high a temperature. The mix was then dumped into a suitable container, where its temperature was again recorded, and from which it was fed to the roll press or the plunger press. The briquettes were then collected and allowed to stand for four days before the rattler loss and density were determined.

The rattler test consists of placing about 2000 grams of briquettes in a drum which is then revolved two hundred times at 32 r.p.m. This test is substantially that adopted for testing paving bricks by the American Society for Testing Materials. The drum is 25 inches long and 30 inches outside diameter and is built of cast-iron plates 6 inches wide, 25 inches long and 1/4 inch apart. The material rubbed off the briquettes as the drum revolves falls out between the plates, and the percentage loss of weight is determined by weighing the rumbled briquettes. The rattler test appears to provide a satisfactory criterion of the handling quality of the briquettes. A briquette that is otherwise satisfactory and does not lose more than 20 per cent in the rattler test is regarded as strong enough to be handled and shipped.

(1) The Use of Luscar Coal.

The results obtained with Luscar coal are given in Table VI.

Table VI

Record of Runs, Briquetting Tests - Luscar Coal

Run No.	M.R. Binder	M.R. H_2O	Temperature °C.				Rattler Loss %	Apparent Specific Gravity
			Coal	Binder	Mix	Pressing		
1257	3.0	8	123	255	138	92	29.6	1.21
1266	3.0	8	129	263	139	92	28.3	1.22
1256	3.5	8	128	252	138	92	20.5	1.22
1265	3.5	8	126	256	136	92	22.9	1.22
1255	4.0	8	130	250	137	90	20.7	1.21
1264	4.0	8	126	267	139	92	18.0	1.22
1267	4.0	8	126	236	137	91	17.6	1.22
1254	4.5	8	119	216	128	92	16.4	1.22
1263	4.5	8	126	273	138	92	16.3	1.22
1253	5.0	8	118	202	126	86	11.9	1.21
1262	5.0	8	125	265	138	90	11.9	1.22
1252	5.5	8	117	197	126	86	11.2	1.22
1261	5.5	8	126	258	142	92	11.9	1.22
1251	6.0	8	120	190	126	85	10.2	1.22
1260	6.0	8	126	254	140	93	12.7	1.22
1268	6.0	8	129	247	142	92	11.8	1.23
1250	6.5	8	120	185	132	75	10.3	1.24
1259	6.5	8	126	240	137	91	9.9	1.23
1249	7.0	8	121	185	126	96	10.3	1.20
1258	7.0	8	125	254	136	93	8.8	1.22

In all the runs made, the mix pressed very well and the briquettes had a hard smooth shiny surface. The above results indicate that it should be possible to make a briquette on an industrial scale using only a proportion of asphalt equivalent to a mixing ratio of 4, that is 3.8 per cent by weight of the total material. Increasing the asphalt content to 4.8 per cent by weight of the total mixture reduces the rattler loss from 19 to 12 per cent and any increase in the asphalt content beyond this does not give any further appreciable reduction.

(2) The Variation in Asphalt Content of Briquettes Made on Industrial Scale

In order to gain experience in briquetting on an industrial scale, a period of three weeks was spent assisting in the operation of the Brazeau Briquetting Plant. This gave an opportunity for large scale experiments to be made on the effect of variation of the asphalt content on the strength of a briquette.

A small briquetting plant was installed when the Brazeau Collieries were faced with a loss of markets because of the excessive amounts of fine coal produced during the handling and transportation of the coal mined by this company. Since the commencement of operations the briquetting plant has been considerably extended and at present there are four briquetting presses in use with a daily output of 1050 tons. Each press has its own blending system consisting of a preheater, a mixer and a fluxer. The purpose of the fluxer is to ensure thorough blending of the constituents of the briquettes. The asphalt is emulsified with steam and apportioned to the coal in the mixer through a special metering device. As far as could be observed there was no tendency for the briquettes to stick to the rolls as has

been the experience with the presses installed by the Research Council. Presumably the quantity and manner in which the moisture was added had a marked effect on the freeing of the briquettes from the presses. It should be mentioned here that a vertical fluxer was tried out in the laboratory and was found to be unsatisfactory as a batch mixer because the temperature could not be controlled easily. Also the particles of coal coated with the binder were abraded and fresh surfaces were thus created which did not receive any coating with the binder and in this way the quality of the briquette was reduced.

The four presses at Brazeau are all of the roll-type. I was informed that the best metal for making the rolls is a 12% chrome steel. One set of such rolls was installed in 1941 and is still giving very good performance. Table VII contains some production data regarding the four presses.

Table VII
Production Data for the Four Briquetting Presses

Press No.	Shape of Briquette	Weight of Briquette ounces	Thickness of Briquette inches	Output tons/hour
1	oval	1 3/4	1 1/4	9.9
2	pillow	3	1 7/16	13.9
4	oval	2 1/4	1 1/8	19.3
5	pillow	4 1/4-4 3/4	1 11/16	30.0

Owing to the blend being pressed at a temperature of approximately 77°C. the briquettes were too warm to be dropped at once into a storage bin. By using a slow moving belt to transport the briquettes from the briquetting presses to the storage bins and spiral chutes in

the storage bins, any damage was minimized.

A series of runs was made on each of the four presses with varying amounts of asphalt in the mixture, all other operating conditions being kept normal. Samples each of approximately 10 pounds in weight, were taken from every experimental run on the presses. Compression tests were done four days after the briquettes were made. A Komarek-Greaves Briquette Tester was used for this purpose. Later the briquettes were also tested for rattler loss and density as previously described and the amount of asphalt present was determined by extraction of the briquettes with benzene. Approximately 200 grams of briquettes were broken into several pieces which were dried for 1 hour in an electrically-controlled gas-filled oven at 105°C. and then cooled and weighed. The pieces of briquettes were then covered with 200 cc.'s of benzene in a 400 cc. beaker and placed in a hot water bath for 15 minutes, the mixture being stirred occasionally. After allowing the mixture to settle for 30 minutes, the liquid was decanted and two more similar extractions then carried out. The residue was centrifuged in a Dulin Rotarex Separator. The Separator consists of an aluminum bowl mounted on the top of a vertical shaft which is hand-driven. The cover of the bowl is held in place by a centrally placed filler screw which is a funnel-shaped piece which screws into the head of the power shaft and serves also as an inlet for additional solvent as the separation proceeds. A ring of filter paper is used between the cover and the bowl. Surrounding the bowl is a covered catch-basin, draining to a spout so that the treated liquid can be recovered. After placing the residue in the bowl and fitting the ring of filter paper over it, the lid is screwed down tightly. The bowl is then set in

motion and the centrifugal action forces all the liquid through the ring of filter paper at the periphery of the bowl. The process is repeated with fresh benzene admitted through the filler screw until the benzene from the spout runs clear. The previously decanted liquor was also centrifuged and any residue so obtained was treated in a similar manner. The total residue was then allowed to air-dry for two days, dried for one hour at 105°C. cooled and weighed. The loss in weight was taken to be the amount of binder present in the briquettes tested.

Table VIII contains the results obtained.

At Nordegg a compression figure of 150 p.s.i. is regarded as the minimum for a good briquette. In each case the compression test results are averages from tests done on three briquettes. With a few exceptions the range of variation of the results of the tests on these briquettes was ± 10 p.s.i. and this variation was adopted as the maximum variation allowable. Any results showing differences exceeding this tolerance were discarded. It is noteworthy that in the tests made briquettes having compression strengths of at least 150 p.s.i. contained a different percentage of asphalt according to the press in which they were made. In No. 5 press less than 3 per cent of asphalt was required, in No. 2 press 4 1/2 per cent, in No. 1 press approximately 4 1/2 per cent for the second series and in No. 4 press 7 1/2 per cent.

The values obtained in the above compression tests for the first series of briquettes made on No. 1 press were considered to be decidedly low and accordingly a second series of tests was carried out. The management of the Brazeau Collieries expressed the opinion that the briquettes would be much improved in strength if a larger amount of

Table VIII

Results of Tests on Briquettes Made at the Brazeau Briquetting Plant

	#1 Press							
	1st Series				2nd Series			
Meter set for - % Binder	2	3	5	7	2	3	5	7
% Binder Found	2.5	2.5	4.2	5.9	-	-	-	6.6
Compression Test - p.s.i.	30	40	50	100	30	105	160	210
Rattler Loss %	92.8	79.4	28.9	10.2	-	-	-	4.0
Apparent Density	1.25	1.24	1.23	1.26	-	-	-	1.22
% Moisture	0.45	0.55	0.45	0.52	-	-	-	0.62

	#2 Press			#4 Press			#5 Press			
Meter set for - % Binder	3	5	7	3	5	7	2	3	4	6
% Binder Found	2.5	4.6	6.7	3.7	4.9	7.4	2.7	3.4	4.4	5.5
Compression Test - p.s.i.	90	160	175	80	90	150	180	185	245	270
Rattler Loss %	87.6	19.1	6.5	23.2	15.6	3.5	35.6	34.5	17.1	8.6
Apparent Density	1.25	1.23	1.23	1.23	1.23	1.23	1.23	1.26	1.26	1.21
% Moisture	0.56	0.59	0.56	0.50	0.53	0.55	0.69	0.64	0.62	0.67

steam was used in both the mixer and the fluxer. No facilities were available to measure the quantity of steam actually used. The second series was made with all steam valves wide open, otherwise the procedure was identical with that used in the first series of tests. The results of the compression tests on the briquettes made in the second series have been given above in Table VIII which affords a ready comparison with the results of the first series of tests. The improvement in strength may be explained by assuming that in the plant during the mixing of the first batch of material the temperature obtained was not high enough to allow the asphalt to flow easily and to coat the particles of coal with an even adhesive film.

The degree of fluidity of the asphalt must be an important factor in the filming of the individual particles of coal which is essential before they can adhere to one another. The plasticity of a material is a function of both pressure and temperature, that is to say in briquetting the asphalt will tend towards greater fluidity under increased pressure or temperature. It would seem that there must be an optimum condition of pressure and temperature regarding the fluid and adhesive properties at which in the formation of briquettes the coal particles are filmed with a minimum quantity of adhesive material. This obviously raises the question of the examination of the properties of an asphalt which are essential in the manufacture of briquettes as well as the adsorptive powers of the coals being briquetted. Unfortunately time has not permitted study of this problem.

The briquettes made on the four presses at Nordegg are all tested on the same compression tester and are considered suitable for handling if they withstand a pressure of 150 p.s.i. Assuming that the degree of mixing is uniform in all cases, the effect of size and shape of a briquette on its compression strength is indicated in the results of the compression tests which were made at Nordegg. It will be seen that No. 4 press which required the largest amount of asphalt, 7 1/2 per cent, to produce a briquette capable of withstanding a pressure of 150 p.s.i. produces the thinnest briquette and No. 5 press which required the smallest amount of asphalt, less than 3%, produces the thickest briquette. Although the test may be satisfactory for briquettes made by one press, it is not necessarily satisfactory for testing briquettes made on presses producing briquettes which differ in size and shape.

The rattler test which uses approximately 2000 grams of briquettes, that is to say between 20 and 40 complete briquettes, does not give such large variations. This is shown in Table VI (page 40) where the maximum difference of 3.1 per cent was obtained using three separate batches of briquettes made with the same amount of asphalt. In the Research Council laboratories a loss on the rattler test of less than 20 per cent is considered essential. If the binder content was related to a rattler loss of less than 20 per cent, this figure only varies from about 4 to 5 per cent for the four presses.

It is also noteworthy that the screen analyses of the extracted material, mentioned above, approach a straight line when plotted on a semi-logarithmic scale. Stansfield and Lang(11)

arrived at the conclusion that the best screen analysis of coals for briquetting was one that approached a straight line when the screen sizes were plotted on a logarithmic scale, providing there was not too much coarse or fine coal. A coal having such an analysis usually gave a strong briquette as judged by the rattler test. Figure XVI is typical of the results obtained on the extracted material from the Brazeau briquettes.

Conclusion

The results obtained indicate that on an industrial scale satisfactory briquettes can be made with coal from the Luscar and Nordegg areas using approximately 5 per cent asphalt. The briquetting presses should be capable of exerting a pressure of approximately 4000 p.s.i. The results also indicate that a large steady supply of steam is of considerable importance in the production of a good quality briquette. The compression test as it is done at Nordegg is not necessarily a satisfactory method for determining the handling qualities of the briquettes made on the four presses.

Figure XVI

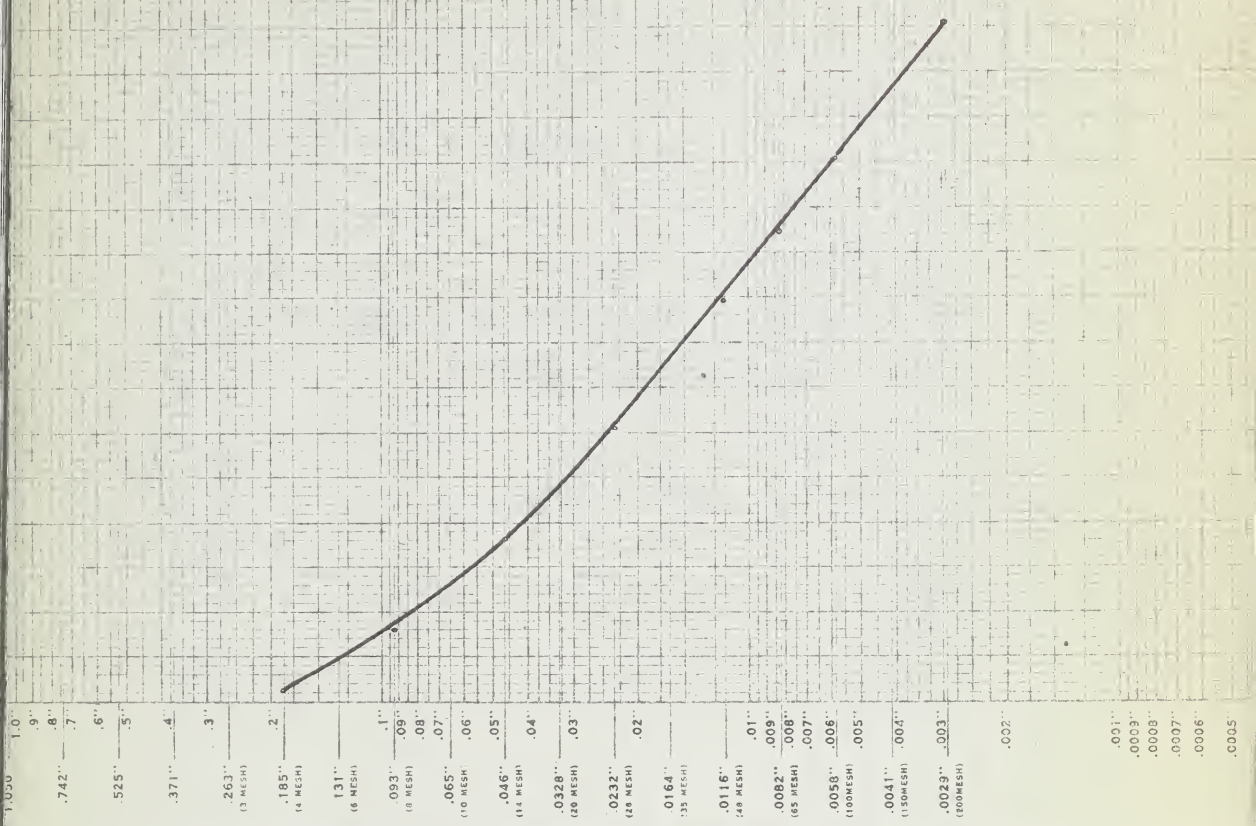
The Tyler Standard Screen Scale

Form No. L-5
Please mention above when ordering.

nulative Logarithmic Diagram of Screen Analysis on Sample of

ne Date

TYPICAL SCREEN ANALYSIS OF EXTRACTED MATERIAL FROM BRAZEAU BRIQUETTES



HE SCREEN THROUGH O FIRST INING EEN	SCREEN SCALE RATIO 1.414				WEIGHTS			ASSAYS			CONTENTS			% OF TOTAL CO
	OPENINGS		MESH	DIAMETER WIRE INCHES	SAMPLE WEIGHTS	PER CENT	PER CENT CUMULATIVE WEIGHTS							
	INCHES	MILLIMETERS												
	1.050	26.67		.149										
	.742	18.85		.135										
	.525	13.33		.105										
	.371	9.423		.092										
	.263	6.680	3	.070										
	.185	4.699	4	.065		1.1	1.1							
	.131	3.327	6	.036										
	.093	2.362	8	.032		6.9	8.0							
	.065	1.651	10	.035										
	.046	1.168	14	.025		10.1	18.1							
	.0328	.833	20	.0172										
	.0232	.589	28	.0125		12.4	30.5							
	.0164	.417	35	.0122										
	.0116	.295	48	.0092		13.9	44.4							
	0082	.208	65	.0072		7.9	52.3							
	0058	.147	100	.0042		8.1	60.4							
	.0041	.104	150	.0026										
	.0029	.074	200	.0021		15.0	75.4							
	0029	074	200	.0021		24.6	100.0							
				TOTALS.										

SECTION 3

BRIQUETTING FOLLOWED BY A PROCESS OF LOW TEMPERATURE CARBONIZATION

Briquetting Followed by a Process of Low Temperature Carbonization

The principal objection to the use of briquettes is the smoke which results on combustion. A great deal of experimental work has been done and a number of processes tried out on an industrial scale in the effort to overcome this disadvantage. The results in most cases, however, have been very discouraging. The briquettes were not strong enough to withstand normal handling. Especially when inorganic binders have been used, the increase in ash content has resulted in a very low grade fuel being produced. Carbonization of course means that the solid product will be higher in ash content than is the uncarbonized briquette.

With uncarbonized briquettes the presence of a certain proportion of higher rank coking coal prevents the disintegration of a briquette when burned on a fire; on heating the higher rank coal, it cokes and helps the briquette to retain its shape. If the briquettes are to be carbonized it is essential that a certain proportion of coking coal should be present if a carbonized product is to be obtained which will withstand a reasonable amount of handling and which will not disintegrate on combustion.

Carbonization may be carried out at low or high temperature. Low temperature carbonization means carbonization at temperatures not exceeding about 700°C. High temperature carbonization means carbonization in general at temperatures exceeding 900 to 1000°C. In any

carbonization process the quantity and quality of the products depend not only on the final carbonization temperature obtained but also on the rate of heating and especially in the case of the volatile products the rate at which these are removed from the retort or oven.

Different processes are therefore possible for producing a clean smokeless fuel:

(a) Low rank coal may be carbonized at a low temperature in order to upgrade it. The resulting char after admixture with a suitable proportion of coking coal and asphalt and briquetting may then be carbonized at a low or high temperature.

(b) The upgrading process may be an integral part of the whole carbonization process at a low or high temperature.

With regard to (a) no account appears to be given in the literature for experiments in which this procedure has been followed, but I have been given to understand that experiments carried out in the laboratories of the Research Council of Alberta have shown that the char from the low temperature carbonization of a low rank coal requires 2-4 per cent more asphalt than the uncarbonized coal alone. The char is exceedingly porous and excessive abrasion occurs during briquetting. Moreover, the procedure would involve two separate carbonizations. My investigations therefore concentrated on (b) above.

Six runs of briquettes were made on the plunger press using four different coals, namely: Drumheller coal, Camrose coal, Crowsnest coal and Mountain Park coal. The composition of these coals is given in Table IX.

Table IX

Analysis of Coals Used in Briquetting and Carbonization

		Per cent Ash	Per cent Net Volatile Matter	Per cent Moisture as analysed	Calorific Value B.t.u.
non-coking	Drumheller coal	8.7	33.0	8.7	10,370
non-coking	Camrose coal	4.5	29.7	23.5	9,250
coking	Crowsnest coal	13.1	24.5	1.2	13,030
coking	Mountain Park coal	12.0	28.7	1.2	13,390

The two non-coking coals, Drumheller and Camrose, were crushed to approximately one-quarter inch size and then dried on a steam table to a moisture content of approximately 4 per cent. These coals were dried because briquettes made with a high moisture content disintegrate easily and do not stand firing or handling (12). The steam table, 4 feet by 5 feet, is located in the laboratories of the University Department of Mining Engineering and uses steam at 10 p.s.i. The drying occupied two days with each sample. The coking coals, Crowsnest and Mountain Park, were ground in a hammer mill using a screen marked "50" which corresponds to 1 mm. opening. The appropriate amounts of the coking and non-coking coals for each run consisting of 8 kilograms were weighed out and placed in the helical mixer (page 36). The procedure followed from this point on has been described earlier (page 38). The amount of asphalt used was kept constant throughout these six runs at 7 M.R. Table X contains the briquetting data and the results of tests and analyses made on the briquettes from each run. Blends of 70 per cent non-coking coal and 30 per cent coking coal were used for runs 1354 to 1356 inclusive because the carbonization results

Table X
Briquetting Data and the Results of Tests and Analyses made on the Briquettes

Run No.	Non-coking Coal	%	Coking Coal	%	% Moisture	% Net Volatile Matter	% Ash	Calorific Value B.t.u.	Compression Strength p.s.i.
1352	Drumheller	90	Crowsnest	10	3.9	36.5	7.6	11,560	195
1351	Drumheller	80	Crowsnest	20	4.7	35.3	9.5	11,580	105
1353	Drumheller	70	Crowsnest	30	3.2	34.4	8.9	11,940	165
1354	Drumheller	70	Mountain Park	30	3.4	34.0	9.1	12,000	155
1355	Camrose	70	Mountain Park	30	4.4	35.1	7.7	12,340	130
1356	Camrose	70	Crowsnest	30	4.4	36.0	7.8	12,260	170

obtained on briquettes from runs 1351 to 1353 inclusive indicated that this blend gave a better product when carbonized than those containing either 10 or 20 per cent coking coal.

Two series of carbonization were carried out on each run of briquettes with different rates of heating. The carbonization temperatures ranged from about 500°C. to approximately 900°C. in stages of 100 or 200°C. In the first series the temperature was raised as quickly as possible to the desired temperature while in the other series a lower rate of heating was employed. For the first series the rheostat under the electric muffle furnace used was cut out completely and in the second one approximately 50 per cent of the rheostat was used but the rate of increase was never allowed to drop below 50°C. in fifteen minutes. The time required to reach the desired temperature and the temperature obtained were recorded. On the following figures (figures XXI - XXIV inclusive) the results obtained for the first series are indicated by (A) and the second series by (B). Figure XVII shows averaged rates of heating for the two series. In Series (A) it was impossible to duplicate exactly the rate of heating.

The carbonization was carried out in the furnace using the carbonizing retort shown in Figure XVIII. For the first experiments four briquettes were carbonized in each case. It was found that the shrinkage of the briquette in the front part of the retort was less than that of the other three briquettes, indicating that the heating of the retort was not uniform. Accordingly in later experiments only three briquettes were carbonized at one time. The position of the

Figure XVII

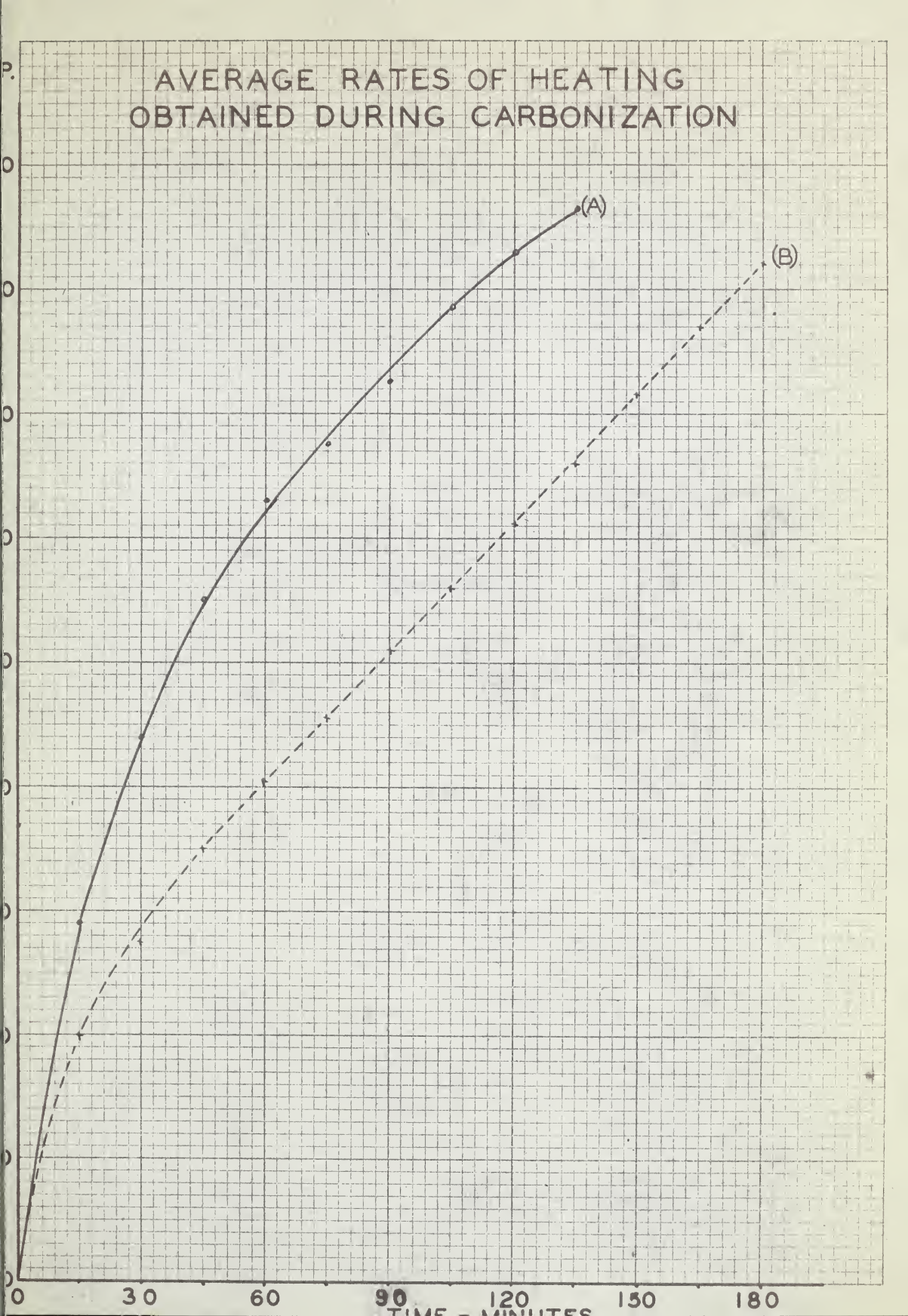
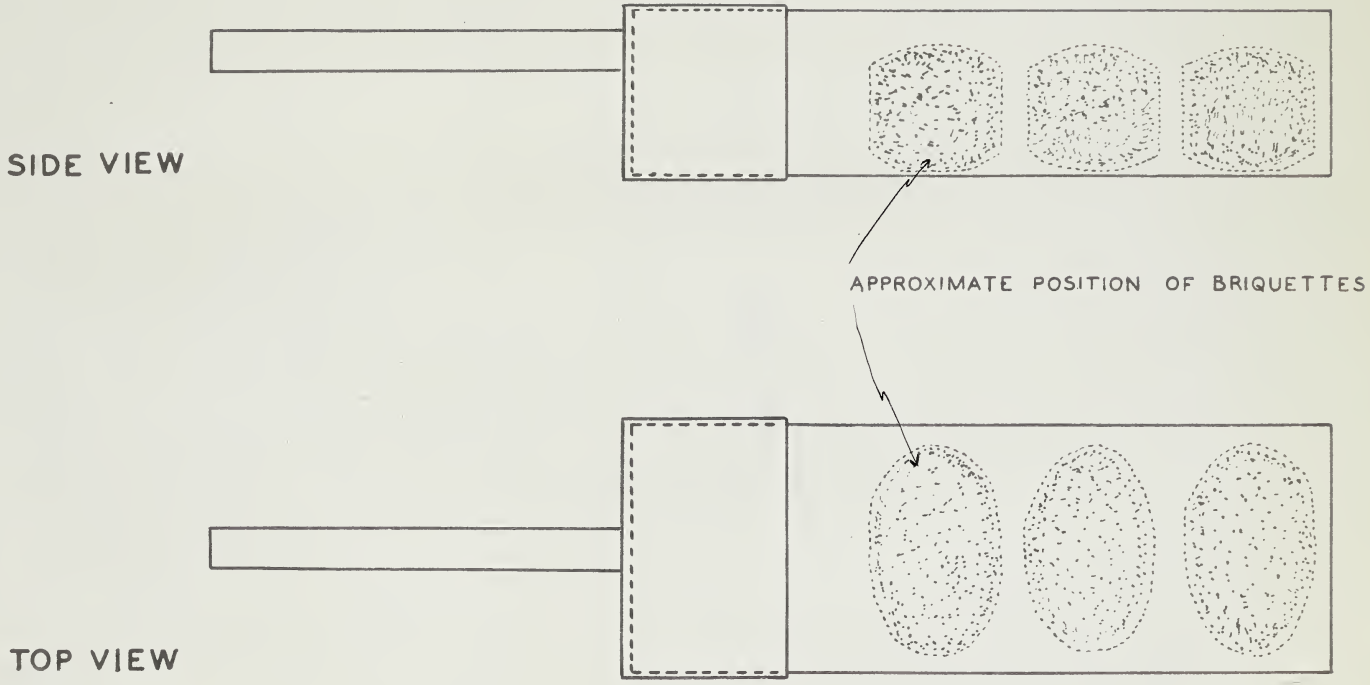

AVERAGE RATES OF HEATING
OBTAINED DURING CARBONIZATION
(A)
(B)
0
30
60
90
120
150
180
TIME - MINUTES

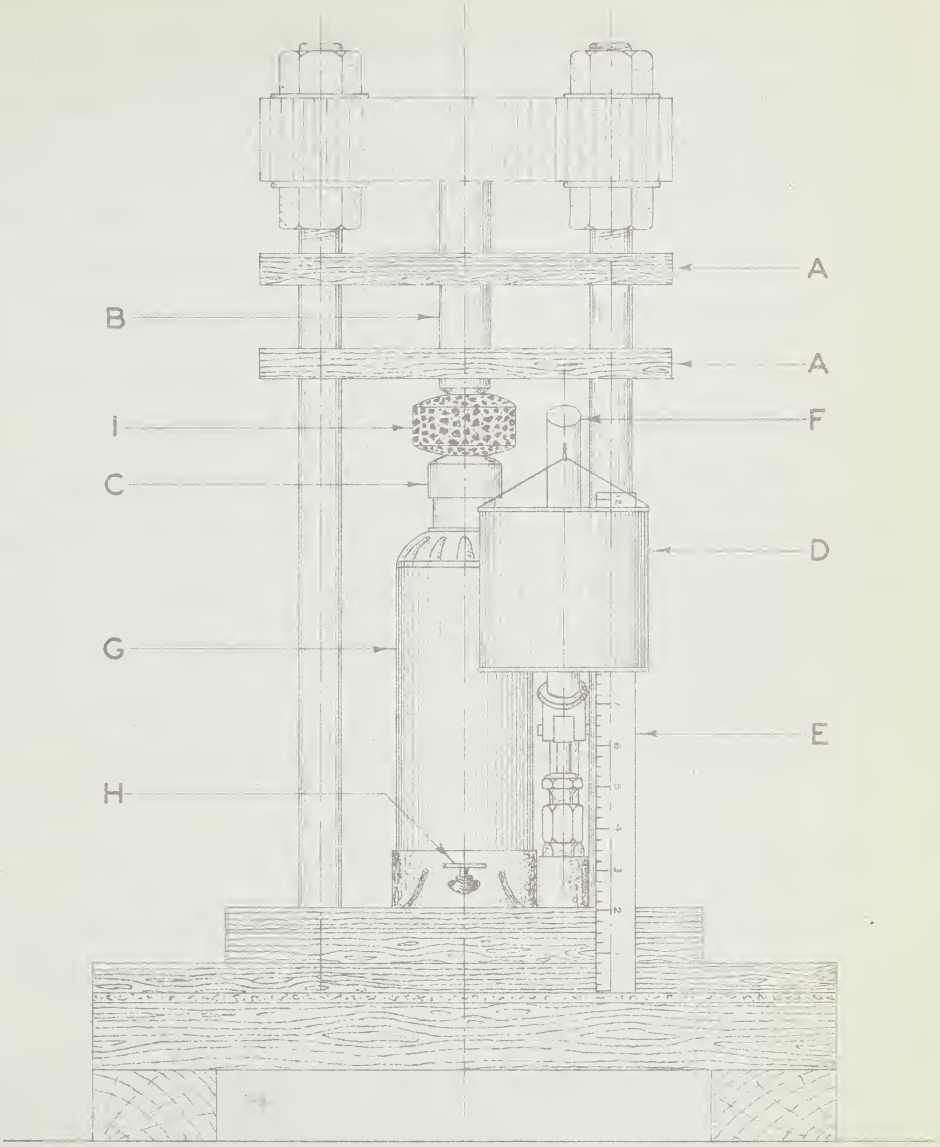
Figure XVIII



CARBONIZING RETORT

(LINEAR MEASUREMENTS 1/2 ACTUAL SIZE)

Figure XIX



HYDRAULIC COMPRESSION BRIQUETTE - TESTING APPARATUS.

briquettes in the retort are shown in FigureXVIII. The individual briquettes were weighed and measured for length, width and thickness before being placed in the carbonizing retort. The filled retort was then placed in the cold furnace and the temperature of the furnace was raised to the desired value and this temperature was maintained for thirty minutes. The retort was then withdrawn and allowed to cool. The carbonized briquettes were weighed and measured as before. They were tested for compression strength and their apparent specific gravity was determined.

It was decided that since all the briquettes had been made on the same press a compression test would give a satisfactory comparison of the strength of the briquettes. Accordingly, the small Hydraulic Compression Briquette-Testing Apparatus, shown in Figure XIX was designed. The various parts of this compression apparatus are described below:

The two pieces of wood (A) are used to hold rod (B) in place.

The steel rod (B) is 7 inches long and has a diameter of 1 1/4 inches. The lower end of this rod has a bevelled edge, this bevelling being made to a 3/4 inch diameter.

The steel cap (C) sits over the top of a Hydraulic Press (G). It has an overall length of 1 inch and a diameter of 1 3/4 inches. A hole 1 1/2 inches in diameter is drilled in the bottom of this cap to a depth of 1/2 inch to allow the cap to fit over the top of the press. The upper edge is bevelled in the same manner as that at rod (B).

The container (D) is a can 4 inches high and 4 inches in diameter. It is attached to arm (F) by means of a small hook and a piece of wire. The arm (F) is a wooden rod 13 1/2 inches long and has a diameter of 13/16 inches. It extends into the pump beam 1 1/4 inches. The distance of the hook from the end of the arm is 1/2 inch. Water is run into the can at a slow uniform rate by means of a siphon until the briquette breaks.

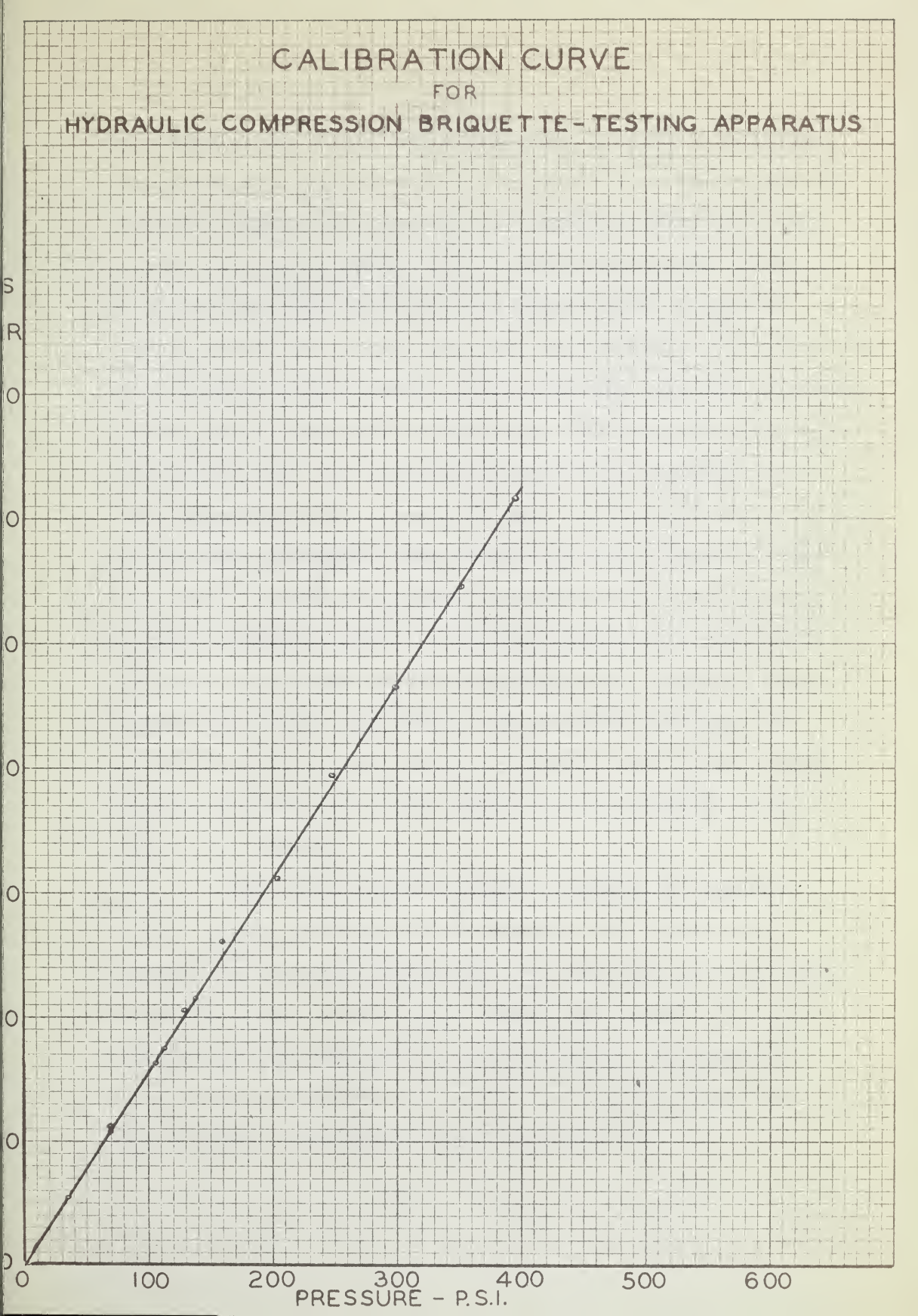
The ruler (E) is used to fix the length of stroke allowed during a compression test. The arm (F) was never lifted above the 11 inch mark and never allowed to go below the 9 1/2 inch mark. These positions were found to give reproducible results.

(H) is a release valve.

The briquette (I), being tested, must be carefully centered before pressure is applied. The apparatus was calibrated by measuring the pressures exerted on a platform scale when different amounts of water were placed in the container (D). Figure XX shows the calibration curve obtained for the apparatus.

The carbonized briquettes were very porous, and the apparent specific gravity could not be determined in the manner previously described. This was shown when one of the carbonized briquettes was placed in water and weighed, the weight increased appreciably owing to penetration of water into the briquette with the displacement of air bubbles. An attempt was therefore made to determine the apparent specific gravity of the carbonized briquettes using a solid material such as sand or rape-seed. Sand or rape-seed

Figure XX


CALIBRATION CURVE
FOR
HYDRAULIC COMPRESSION BRIQUETTE-TESTING APPARATUS
0
100
200
300
400
500
600
PRESSURE - P.S.I.

was allowed to fall freely into a tared quart jar until it overflowed. The contents were levelled off with the top of the jar and the material in the jar weighed. This procedure was repeated at least three times in order to obtain an average value. The apparent specific gravity of the material was thus determined. The average weight of material required to fill the jar was then weighed out and used in the determination of the apparent specific gravity of the briquettes. The flow of material into the jar was interrupted at intervals to allow the briquettes to be placed in the jar. Care was taken to see that the briquettes did not touch one another or the sides of the jar. The material which overflowed was collected and weighed. This procedure was also repeated at least three times. Knowing the apparent density of the material displaced, the apparent specific gravity of the briquettes was thus ascertained. The results obtained were approximately 10 per cent lower than those obtained later using a wax coating method and this discrepancy was not consistent. Rape seed however gave slightly more uniform results but these were still low. This method was not used because it was slow and inconsistent.

A wax coating method was used to determine the apparent specific gravity of the carbonized briquettes. The weight of the briquette was first determined in air. The briquette was then lightly coated with molten paraffin wax by dipping. The weight of the waxed briquette was then determined in air and in water. The density of the paraffin was ~~was~~ assumed to be 0.9. The following formula was used to calculate the apparent specific gravity:(13)

$$\text{Apparent specific gravity} = \frac{Wa}{Wap - Wwp - \left(\frac{Wap - Wa}{0.9}\right)}$$

where Wa = weight of the uncoated briquette in air

Wap = weight of the waxed briquette in air

Wwp = weight of the waxed briquette in water

Some of the results of the various series of carbonizations from Tables XI to XVI are presented graphically in Figures XXI to XXIV inclusive. As mentioned previously, in all the figures the curves marked (A) represent the results obtained with a rapid rate of heating and those marked (B) are the comparable curves for a slow rate of heating. Throughout, the curves for runs 1351-1353 inclusive are for the results obtained with mixtures of Drumheller non-coking and Crowsnest coking coal in varying amounts and are indicated by subscript (1) after (A) or (B) as the case may be. Similarly the curves for runs 1353-1356 inclusive are for results obtained with different blends of coking and non-coking coals. These are identified by subscript (2). For convenience in discussing the significance of these graphs the actual blends are repeated below:

1351- 20 per cent Crowsnest coal and 80 per cent Drumheller coal

1352 10 per cent Crowsnest coal and 90 per cent Drumheller coal

1353 30 per cent Crowsnest coal and 70 per cent Drumheller coal

1354 30 per cent Mountain Park coal and 70 per cent Drumheller coal

1355 30 per cent Mountain Park coal and 70 per cent Camrose coal

1356 30 per cent Crowsnest coal and 70 per cent Camrose coal

Table XI
Results Obtained on Briquettes from Run 1351

Temperature °C.	Time Minutes	Per cent Reduction in Length	Width	Thickness	Per cent Loss of Weight	Apparent Specific Gravity	Compression Strength p.s.i.	Per cent Volatile Matter	Per cent Ash	Calorific Value B.t.u.
Original briquettes						1.08	105	40.0	9.5	11,580
510	60	3.7	4.3	6.5	25.8	1.01	40	19.1	11.9	12,350
510	80	4.6	4.7	6.6	25.4	1.05	50	18.3	12.5	12,470
600	55	5.1	6.7	6.4	30.5	1.01	95	11.6	12.9	12,780
600	125	6.2	6.9	9.0	31.3	1.02	135	11.3	12.9	12,810
700	75	8.2	10.7	9.7	34.5	1.07	115	10.0	14.0	12,760
700	165	9.8	10.2	12.7	34.6	1.10	170	5.6	13.8	12,770
800	85	10.9	12.2	11.7	36.4	1.16	130	4.0	14.5	12,600
800	185	12.0	12.9	14.9	35.7	1.18	215	3.0	15.1	12,500
900	165	12.6	13.9	14.3	36.5	1.20	180	2.6	15.5	12,320
900	205	11.5	13.4	15.4	36.5	1.19	235	2.1	15.8	12,300

Table XII
Results Obtained on Briquettes from Run 1352

Temperature °C.	Time Minutes	Per cent Reduction in Length	Width	Thickness	Per cent Loss of Weight	Apparent Specific Gravity	Compression Strength p.s.i.	Per cent Volatile Matter	Per cent Ash	Calorific value B.t.u.
Original briquettes						1.10	195	40.4	7.6	11,560
500	40	3.3	4.3	7.6	24.1	1.06	15	20.9	9.5	12,470
500	90	4.4	5.3	7.6	26.1	--	20	18.3	10.0	12,560
600	50	6.2	8.0	7.5	33.5	1.01	50	10.0	11.1	13,160
600	130	7.1	8.4	9.7	33.6	1.03	65	8.7	11.3	13,200
710	60	9.9	11.3	10.9	36.5	1.09	50	4.6	11.8	13,020
700	150	9.8	10.5	12.6	35.7	--	105	5.7	11.6	13,140
800	90	11.5	12.6	13.3	37.7	1.13	60	3.3	12.3	12,860
800	185	12.7	13.4	15.5	37.4	1.15	100	3.2	12.4	12,920
900	145	12.6	13.7	14.4	38.4	1.22	100	1.9	12.9	12,650
900	210	13.3	14.4	15.2	37.6	1.23	135	2.2	12.8	12,630

Table XIII
Results Obtained on Briquettes from Run 1353

Temperature °C.	Time Minutes	Per cent Reduction in Length	Width	Thickness	Per Cent Loss of Weight	Apparent Specific Gravity	Compression Strength p.s.i.	Per cent Volatile Matter	Per cent Ash	Calorific Value B.t.u.
Original briquettes						1.06	165	37.4	8.9	11,940
510	40	3.1	2.1	5.2	19.3	1.06	65	21.6	10.8	12,370
500	85	4.1	3.6	6.7	23.4	1.06	170	16.5	11.4	12,590
600	75	5.4	5.6	6.6	29.3	1.01	140	11.6	12.4	12,850
600	145	6.2	6.6	9.1	29.8	1.04	230	8.7	12.5	13,060
700	65	8.3	9.5	9.1	33.2	1.07	180	5.4	12.9	12,960
710	145	9.7	9.7	12.0	33.4	1.07	330	4.1	13.1	12,880
900	105	12.9	14.2	14.2	35.5	1.22	320	1.6	15.7	12,340
900	215	13.3	13.6	16.3	34.3	1.25	>400	1.7	15.0	12,460

Table XIV
Results obtained on Briquettes from Run 1354

Temperature °C.	Time Minutes	Per cent Reduction in Length	Width	Thickness	Per Cent Loss of Weight	Apparent Specific Gravity	Compression Strength p.s.i.	Per Cent Volatile Matter	Per cent Ash	Calorific Value B.t.u.
Original briquettes						1.09	155	37.5	9.1	12,000
500	40	2.1	3.6	7.2	23.9	1.03	205	18.1	9.4	12,440
510	75	4.0	3.9	9.5	25.9	1.03	330	16.3	9.9	12,540
700	65	7.6	9.3	8.7	34.3	1.02	320	5.0	11.3	12,800
710	130	8.5	8.7	14.1	34.0	1.09	>400	4.8	11.6	12,890
900	125	12.9	13.3	14.0	35.9	1.17	>400	1.7	13.1	12,340
900	215	13.4	13.2	18.3	35.6	1.19	>400	1.2	12.4	12,410

Table XV
Results Obtained on Briquettes from Run 1355

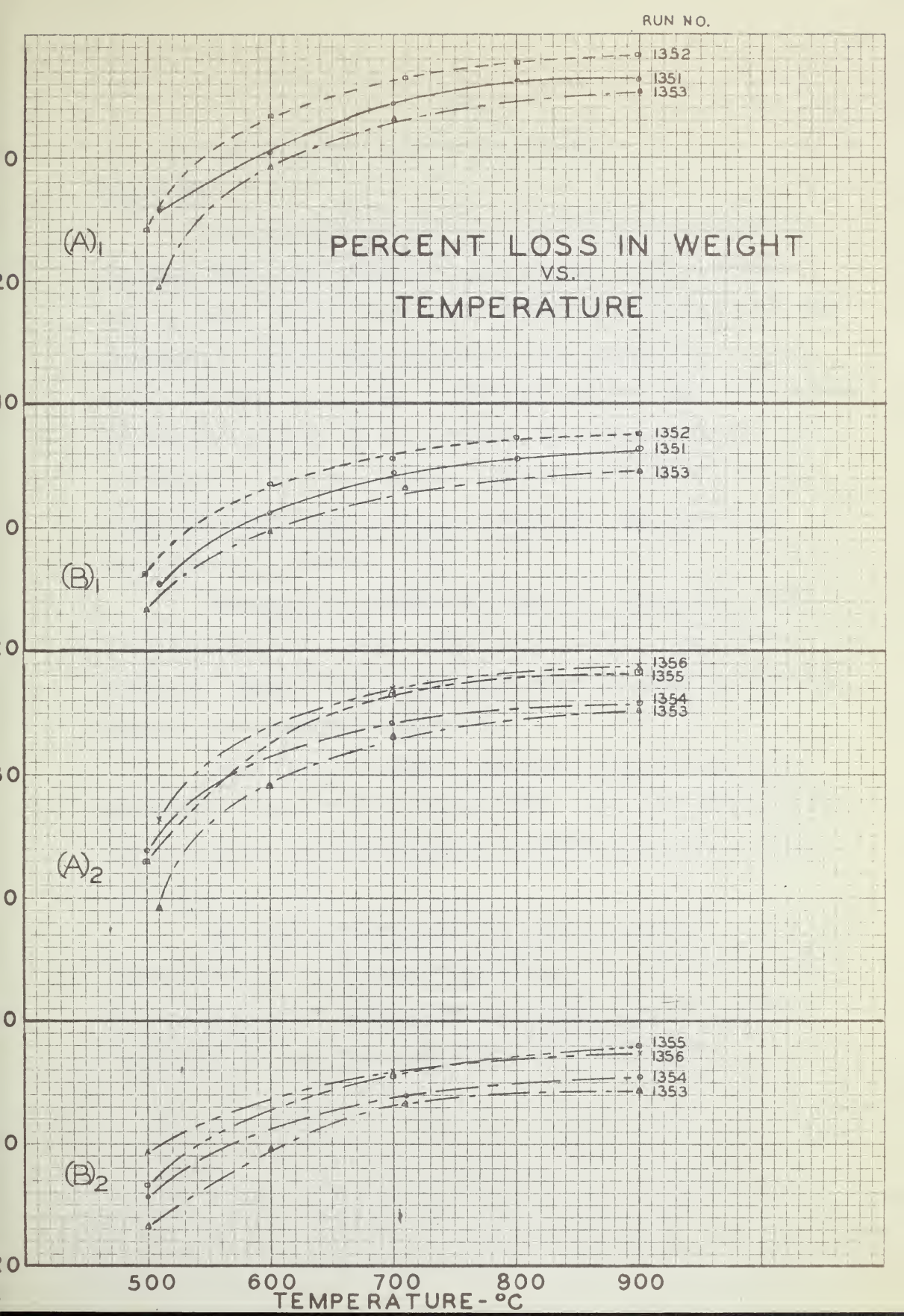
Temperature °C.	Time Minutes	Per cent Reduction in Length	Width	Thickness	Per cent Loss of Weight	Apparent Specific Gravity	Compression Strength p.s.i.	Per cent Volatile Matter	Per Cent Ash	Calorific Value B.t.u.
Original briquettes						1.05	130	39.5	7.7	12,340
500	40	0	0	7.8	23.0	1.01	140	22.4	9.4	12,660
500	80	2.1	1.7	9.9	26.7	1.01	300	16.9	9.9	12,800
700	65	6.7	8.2	8.8	36.7	1.01	185	6.0	11.3	13,190
700	145	7.4	8.2	13.1	35.7	1.01	360	4.9	11.6	13,070
900	130	12.2	12.6	13.8	38.6	1.09	315	2.0	13.1	12,740
900	205	12.3	12.4	17.2	38.0	1.13	>400	2.5	12.4	12,820

Table XVI
Results Obtained on Briquettes from Run 1356

Temperature °C.	Time Minutes	Per cent Reduction in Length	Width	Thickness	Per cent Loss of Weight	Apparent Specific Gravity	Compression Strength p.s.i.	Per cent Volatile Matter	Per cent Ash	Calorific Value B.t.u.
Original briquettes						1.06	170	40.5	7.8	12,270
510	40	2.2	3.0	5.5	26.5	1.01	45	20.2	9.8	12,790
500	70	4.9	4.2	6.5	29.6	1.03	110	15.2	10.2	12,920
715	70	9.7	10.3	10.7	37.0	1.02	160	5.2	10.0	13,090
700	150	9.7	10.6	11.9	35.8	1.04	165	5.2	11.4	13,220
900	130	13.1	13.7	14.3	38.6	1.14	330	1.5	12.7	12,870
900	195	13.5	12.7	16.4	37.5	1.16	>400	2.2	12.6	12,870

Carbonized briquettes exposed to the atmosphere for a considerable period and then analysed showed that they did not contain any appreciable quantity of moisture. In certain cases a small increase in weight occurred during the moisture determination which was carried out in an atmosphere of natural gas at a temperature of 105°C.

Figure XXI


RUN NO.
1352
1351
1353
(A)1
PERCENT LOSS IN WEIGHT
VS.
TEMPERATURE
1352
1351
1353
(B)1
1356
1355
1354
1353
(A)2
1355
1356
1354
1353
(B)2
500
600
700
800
900
TEMPERATURE - °C

The results of the graphs are dealt with in turn.

Figure XXI

All the curves show that the carbonization at a temperature exceeding 700°C. only results in a small increase in the percentage loss in weight. This of course does not make any reference to the other properties of the briquettes prepared at these temperatures. A temperature of 700°C. can be taken as that temperature at which substantially all the tar and liquor has been evolved. The loss shown between 700°C. and 900°C. is thus represented as a loss due to the evolution of gas which will contain large quantities of hydrogen. This gas will be relatively low in calorific value.

Increasing the quantity of coking coal increases the yield in carbonization at a low and a high rate of heating. The maximum difference obtained in these experiments was of the order of 4 per cent whatever the carbonization temperature.

Below 700°C. the yield of carbonized briquettes increases rapidly as the temperature approaches 500°C. The actual difference in the yield of the carbonized briquettes at 500°C. and 900°C. is of the order of 16 per cent.

The $(A)_2$ curves show that the yield of briquettes appears to depend principally on the kind of non-coking coal. It is more marked in the regions of low temperatures. No standard test was available for determining the caking index of the coking coals used.

Figure XXII

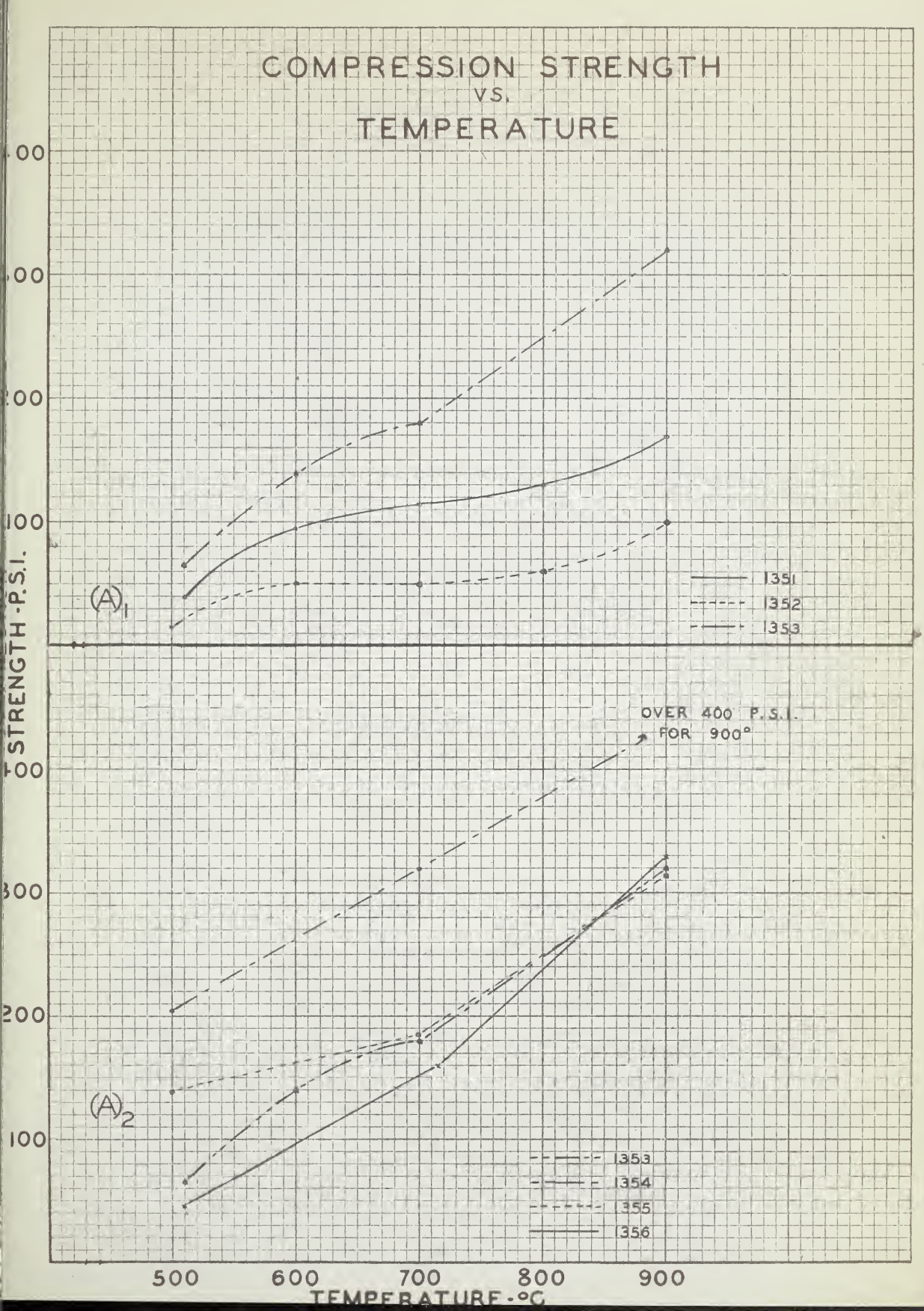
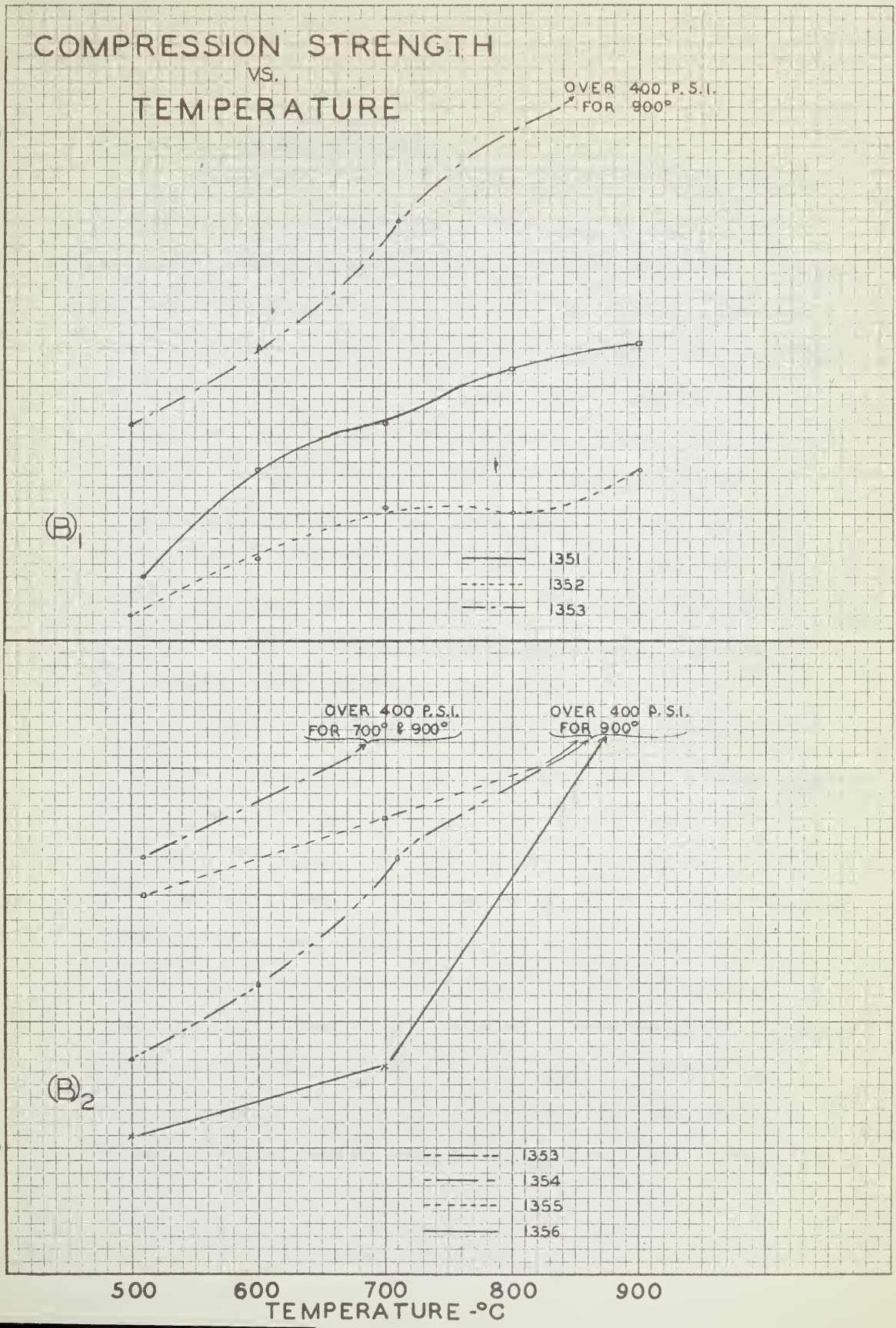

COMPRESSION STRENGTH
VS.
TEMPERATURE
STRENGTH - P.S.I.
(A)1
1351
1352
1353
OVER 400 P.S.I.
FOR 900°
(A)2
1353
1354
1355
1356
500
600
700
800
900
TEMPERATURE - °C

Figure XXII continued


COMPRESSION STRENGTH
VS.
TEMPERATURE
OVER 400 P.S.I.
FOR 900°
(B)1
1351
1352
1353
OVER 400 P.S.I.
FOR 700° & 900°
OVER 400 P.S.I.
FOR 900°
(B)2
1353
1354
1355
1356
STRENGTH-P.S.I.
500
600
700
800
900
TEMPERATURE -°C

Figures XXII and XXII continued

Compression strength increases with temperature. Referring to curves $(A)_1$, as the percentage of coking coal is increased the compression strength increases but not in a direct proportion. At 500°C. the compression strength is very low and it is not until a temperature of at least 600°C. is reached that the briquettes have any appreciable compressive strength. If one is to judge by the former criterion of the experiments at Nordegg, a briquette of sufficient strength might be prepared by the carbonization at 700°C. of briquettes containing 30 per cent Crowsnest coal and 70 per cent Drumheller coal. With this blend of the two coals there is a substantial improvement where the carbonization temperature is increased to 800°C. and above. The increase in compression strength for briquettes containing smaller proportions of coking coal is not very great.

Comparison of $(A)_1$ and $(B)_1$ shows that the slower rate of heating has a marked effect on the compressive strength of a carbonized briquette throughout the whole range of temperatures and this is particularly the case with the blend containing the maximum amount of coking coal used. That is to say that should it be considered necessary for reasons other than strength, such for example as the ease of combustion, or to obtain the maximum amount of carbonized product from a definite weight of uncarbonized briquettes, to carbonize the briquettes at 700°C. it would be most desirable and perhaps essential on an industrial scale to adopt a slow heating rate. The actual output of the plant would be a major consideration. Alternatively, it might be

pointed out that with a slow rate of heating a satisfactory briquette could be made by carbonizing at 700°C. a blend containing only 20 per cent coking coal as compared to a briquette made from a blend containing 30 per cent coking coal if the carbonization were carried out faster. The compression strength of a briquette made from a blend containing the largest quantity of coking coal and carbonizing, by slow heating, to 900°C. was so high that it could not be measured on the apparatus used.

Curves $(A)_2$ and $(B)_2$ both show that compression strength as distinct from yield appears to depend more on the quality of the coking coal. In both cases the Mountain Park coal will be seen to be superior in this respect. This is not to say that the nature of the non-coking coal is not of great importance because the two curves in $(A)_2$ for the same proportions of Mountain Park coal and the non-coking coals are quite different apparently due to the nature of the non-coking material. The same applies up to 700°C. with a slow rate of heating and the indications are that this effect may be enhanced with carbonization up to 900°C. The $(A)_2$ curves show that with the Crowsnest coking coal the nature of the non-coking coal with a quick rate of heating is not of so great importance. Reference to $(B)_2$, however, shows that this is not so at low heating rates where the poorer quality of the Camrose coal is very marked indeed. From a purely practical view of carbonization as carried out at 700°C., whether the heating rate be slow or rapid, a blend of 70 parts Drumheller coal and 30 parts Mountain Park will produce a briquette which should readily meet all requirements for strength.

In a fairly recent paper (14) the view is expressed that in the coking process the fusible coal bitumens render the mass plastic which phase is of course essential if a hard coherent coke is to be obtained. The remainder of the coal which is infusible varies in adsorptive properties which must be satisfied before the individual particles of coal can become plastic. A connection is therefore drawn between the coking power of a coal and its adsorptive properties as measured by its inherent moisture content or to use what has become a well known term its natural bed moisture or capacity moisture. If this view is correct, one would anticipate that a similar state of conditions applies in the blending of coking and non-coking coals. It is considered that all of the coking coal when it becomes plastic has first to satisfy the adsorptive power of the non-coking coal before the particles of the latter can be filmed on their surfaces and thus adhere to one another. If this is so, non-coking coals of a low capacity moisture would require less coking coal than a non-coking coal of a high capacity moisture content. This view is introduced here because the curves $(A)_2$ and $(B)_2$ in Figure XXII continued show that Drumheller coal gives a better briquette than Camrose coal and the capacity moistures of these two coals are 18 per cent and 25 per cent respectively. The coking process is of course a complex one and must involve not only such considerations as are outlined above but also such factors as the penetrative power, softening point, viscosity and final setting power of the coking materials. Accordingly it is impossible within the scope of this thesis to discuss the fundamental reasons why the slow rate of heating gives such a marked improvement in compression strength.

Figure XXIII

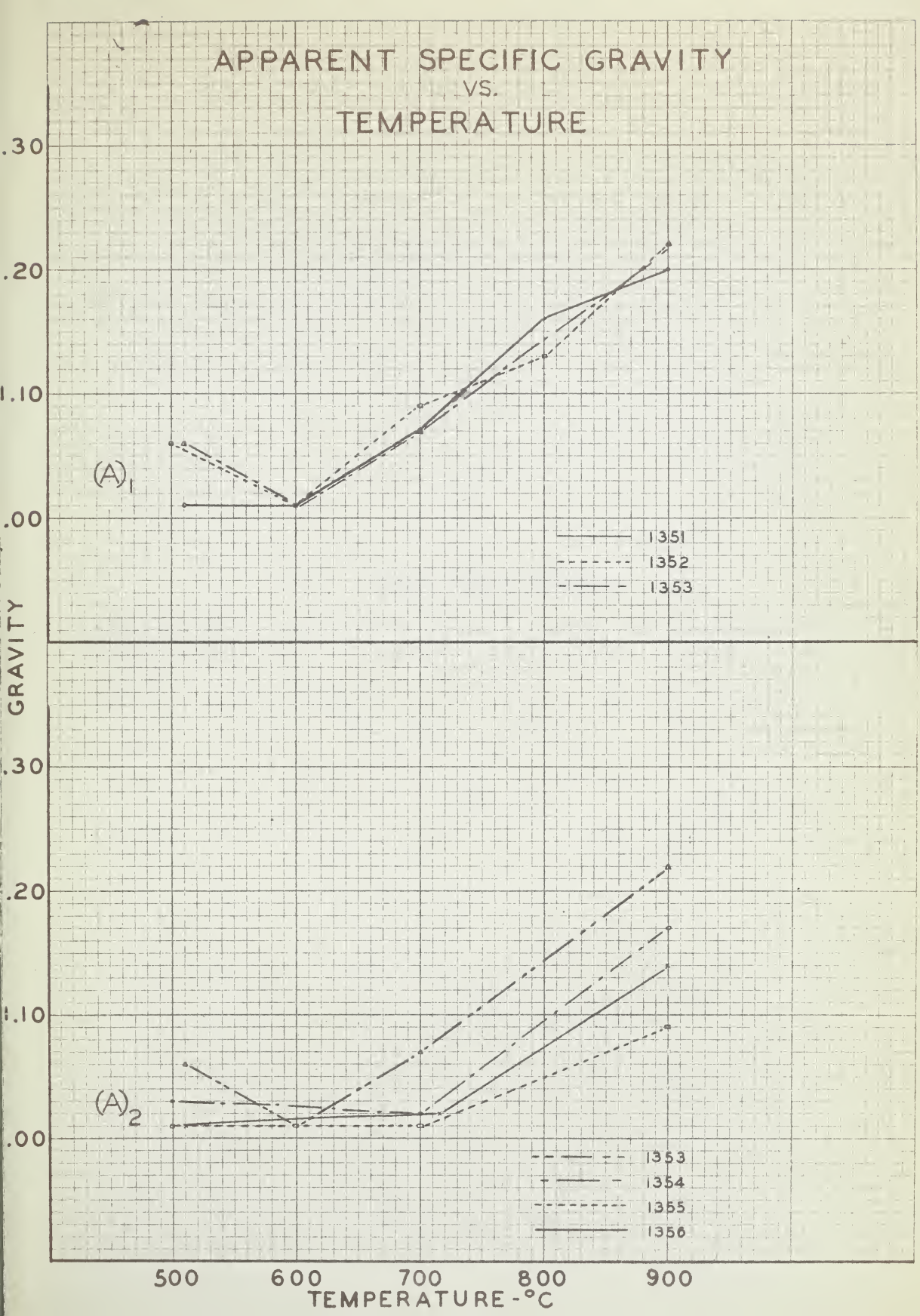
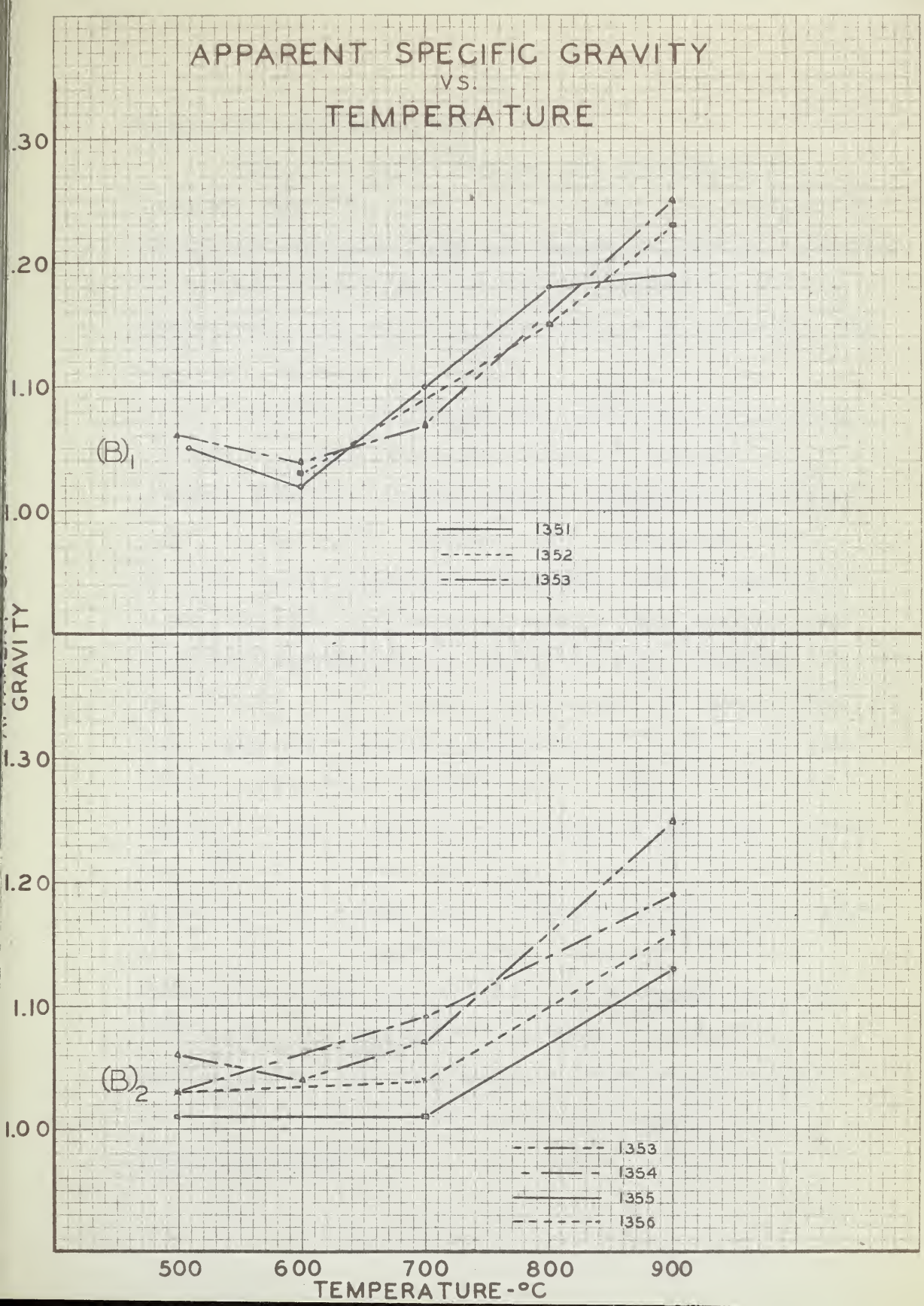

APPARENT SPECIFIC GRAVITY
VS.
TEMPERATURE
.30
.20
1.10
.00
GRAVITY
(A)1
1351
1352
1353
.30
.20
1.10
.00
(A)2
1353
1354
1355
1356
500
600
700
800
900
TEMPERATURE - °C

Figure XXIII continued

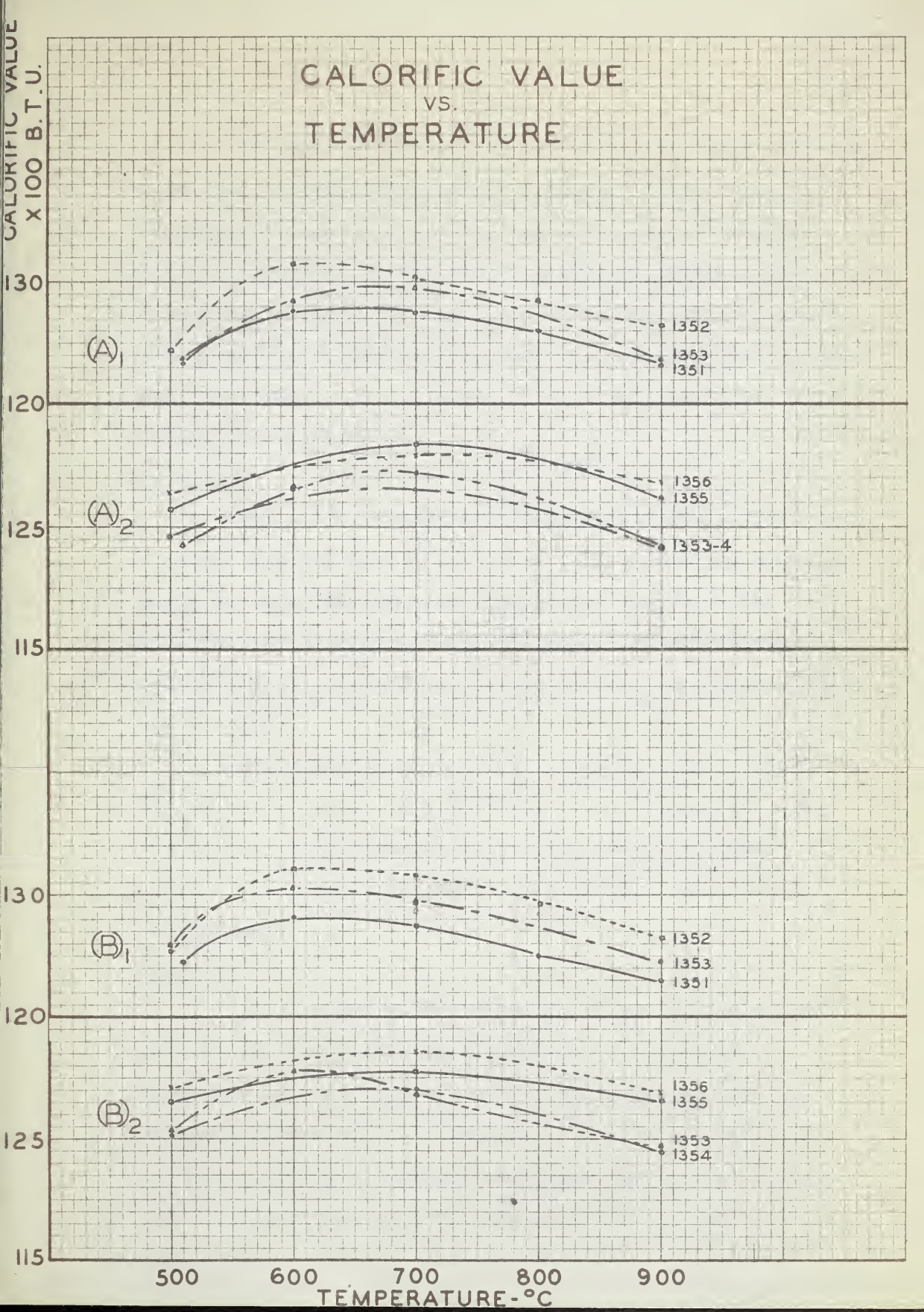

APPARENT SPECIFIC GRAVITY
VS.
TEMPERATURE
.30
.20
1.10
1.00
(B)1
1351
1352
1353
GRAVITY
1.30
1.20
1.10
1.00
(B)2
1353
1354
1355
1356
500
600
700
800
900
TEMPERATURE - °C

Figures XXIII and XXIII continued

Some of the factors which have just been mentioned will presumably apply to the apparent specific gravity of the briquettes and consequently only general trends can reasonably be considered. Comparing $(A)_1$ and $(B)_1$ it will be seen that the rate of heating has not a very marked effect on the apparent specific gravity of the briquettes. This also applies for curves $(A)_2$ and $(B)_2$.

Cobb[15] in studying the solid products of carbonization of a variety of materials ranging from cellulose to anthracite paid particular attention to specific gravity. Carbonization temperatures ranged from about 400°C. in stages of 100° to approximately 1200°C. He states "That the specific gravity whatever it may be initially and in the first stage of carbonization reaches a common value very near 1.4 at 500°; anthracite did not alter in this stage, cellulose diminished from 1.6 and a Welsh meta-bituminous coal increased from 1.23, changes due to differing decompositions. From 500° to 800° the specific gravity always increased from 1.4 to 1.8, but in the stage from 800° to 1200° it remained nearly constant at about 1.85." Curves $(A)_1$, $(B)_1$ and to a lesser extent $(A)_2$, $(B)_2$ show the same general trend. As far as $(A)_1$ and $(B)_1$ are concerned any initial drop to 600°C. is due apparently to completion of the evolution of tar vapors and consequent shrinkage. Above 600° further shrinkage especially above 700°C. is of course characteristic of the carbonization of coal at high temperatures. This shrinkage is due of course to the emission of gas which is principally hydrogen and lesser amounts of carbon monoxide and methane.

Figure XXIV


CALORIFIC VALUE
VS.
TEMPERATURE
CALORIFIC VALUE
X 100 B.T.U.
130
120
125
115
(A)1
1352
1353
1351
(A)2
1356
1355
1353-4
(B)1
1352
1353
1351
(B)2
1356
1355
1353
1354
500
600
700
800
900
TEMPERATURE - °C

The order of the curves in Figures XXIII and XXIII continued is not that in Figures XXII and XXII continued. In other words the compression strength of a briquette does not appear to be simply a matter of shrinkage. In the case of the apparent specific gravity (curves $(A)_2$ and $(B)_2$) the position of the coking coals is reversed to that in the case of compression strength, the non-coking coals however are in the same relative positions. No explanation of this is attempted on the evidence obtained.

Figure XXIV

Briquettes carbonized at a temperature of 600° - 700°C. have a maximum calorific value in the case of the Drumheller and Crowsnest blends (A_1, B_1). The difference in calorific value due to the different rates of heating is not very marked. It will be noticed that the increase in heat value obtained does not compensate for the loss in weight.

With regard to $(A)_2$ and $(B)_2$, presumably each coal used would contribute to the calorific value of the carbonized briquette in proportion to the amounts and calorific values of the cokes prepared from the separate coals at any particular temperature of carbonization.

Conclusion

(1) To obtain the best carbonized product with Drumheller coal, it should be blended with a coking coal and carbonized at about 700°C. at a slow rate of heating. The amount of coking coal required will vary with the coking power. With the two coals used practically the same percentage of coking coal was required but with coals of higher coking power the percentage would presumably be less.

(2) Judged by the compression strength, density and calorific value, a blend of 20 per cent Crowsnest coking coal with 80 per cent Drumheller coal and a slow rate of carbonization will give a satisfactory briquette. Seven mixing ratio of asphalt will be required in briquetting.

(3) A final carbonization temperature of 700°C. is the minimum temperature which should be employed. Carbonization at a somewhat higher temperature would mean an increased density and compressive strength at the expense of a decreased calorific value. Circumstances might justify the higher temperatures but the actual carbonization temperature employed would have to be related to the burning quality of the briquettes.

(4) Camrose coal requires a larger proportion of coking coal if a strong enough product is to be obtained. This proportion amounts to 30 parts of coking coal and 70 parts of Camrose coal as compared to 20 parts of coking coal and 80 parts Drumheller coal. Similar remarks apply to the Camrose coal as to the Drumheller coal with regard to density, calorific value and compression strength.

(5) The actual value of the briquettes to the consumer must obviously depend upon the economics of the carbonization process. This work shows that an enhanced fuel of a smokeless character and a blocky nature can be manufactured by the methods outlined from either Drumheller or Camrose low grade coal.

SUMMARY

SUMMARY

"A" Drumheller coal can be upgraded by any one of the following methods or by a combination of them.

(i) Coal Washing

Laboratory tests have shown that the ash content of the slack coal can be reduced considerably by normal coal cleaning processes. The extent of breakage which might occur if the coal was cleaned in a wet washing process has not been determined.

(ii) Briquetting and Carbonization

A strong smokeless fuel can be obtained by carbonizing a briquetted blend of 80 per cent Drumheller coal, 20 per cent Crowsnest coking coal and 7 M.R. asphalt up to a final temperature of about 700°C. employing a slow rate of heating.

"B" Camrose Coal

Carbonized briquettes of practically equal quality can be obtained with Camrose coal using the same treatment as for Drumheller coal except that 30 per cent of Crowsnest or Mountain Park coking coal is required.

"C" Nordegg coal

Washing tests on Nordegg coal show that it cannot be sharply separated into clean coal and refuse. The smaller sizes can be successfully briquetted using 4-5 M.R. asphalt.

"D" Luscar coal

Briquetting experiments with Luscar coal show that this coal like that of Nordegg requires approximately 5 per cent asphalt to produce a satisfactory briquette.

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